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Miſcellanea Curioſa.

BEING A
COLLECTION
Of ſome of the Principal
PHÆNOMENA
IN
NATURE,
Accounted for by the Greateſt
Philoſophers of this Age.

TOGETHER
With ſeveral DISCOURSES read before
the ROYAL SOCIETY, for
the Advancement of Phyſical and Mathematical
Knowledge.

LONDON:
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MVSEVM
BRITAN
NICVM

TO THE READER.

SOME of the Principal Diſcoveries and Enquiries, both in *Phyſical* and *Mathematical* Learning, being regiſter'd in the Voluminous Journals of the *Royal Society*, are amongſt a multitude of leſs uſeful Matters, ſo Obſcurely hid, that but very few inquiſitive Gentlemen ever ſo much as heard of them.

The Deſign therefore of the enſuing Collection, is to digeſt in a convenient Method, all the moſt curious *Philoſophical* and *Mathematical* Diſcoveries, as they are to be met with, which may any way tend to the Uſe of Life, or Advancement of Arts and Sciences.

And on this Occaſion, it will be convenient to intimate to the Reader;

Firſt, That the Theories and Diſcourſes here collected, have already paſt the Cenſure of the *Learned World*: Who have acknowleg'd them the moſt ſatisfactory Accounts of Nature's Proceedings, wherein ſome of her greateſt Depths are fathom'd, and a Foundation laid for Poſterity to build an infinite *Superſtructure*.

Secondly, That they are related (*Verbatim*) juſt as they were delivered in, or read before the *Royal Society*: For it has been the Opinion of the moſt Judicious amongſt thoſe *Honourable Members*, that it is impoſſible ſo to abridge them, (which are but Abridgments themſelves) as not to render them obſcure and unintelligible.

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Miſcellanea Curioſa.

An Eſtimate of the Quantity of Vapours raiſed out of the Sea, derived from Experiment: Together with an Account of the Circulation of the watry Vapours of the Sea, and of the Cauſe of Springs, preſented to the Royal Society,

By Mr. E. Halley, F. R. S.

THAT the Quantity of Aqueous Vapours contain'd in the Medium of the Air, is very conſiderable, ſeems moſt evident from the great Rains and Snows which are ſometimes obſerv'd to fall, to that degree, that the Water thus diſcharg'd out of the Interſtices of the Particles of Air, is in weight a very ſenſible part of the incumbent Atmoſphere: But in what proportion theſe Vapours riſe, which are the Sources not only of Rains, but alſo of Springs or Fountains (as I deſign to prove) has not, that I know of, been any where well examin'd, tho' it ſeem to be one of the moſt neceſſary Ingredients of a Real and Philoſophical Meteorology, and as ſuch to deſerve the Conſideration of this Honourable Society. I thought it might not be unacceptable to attempt by Experiment to determine the Quantity of the Evaporations of Water, as far as they ariſe from Heat, which upon Trial ſucceeded as follows.

We took a Pan of Water, about 4 Inches deep, and 7 Inches $\frac{9}{10}$ Diameter, in which we placed a Thermometer, and by means of a Pan of Coals, we brought the Water to the ſame degree of Heat, which is obſerved to be that of the Air in our hotteſt Summer; the Thermometer nicely ſhewing it: This done, we affixed the Pan of Water, with the Thermometer in it, to one end of the Beam of a Pair of Scales, and exactly counterpois'd it with weights in the other Scale; and by the application or removal of the Pan of Coals, we found it very eaſie to maintain the Water in the ſame degree of Heat preciſely. Doing thus we found the weight of the Water ſenſibly to decreaſe; and at the end of two hours we obſerved that there wanted half an ounce *Troy*, all but 7 grains, or 233 grains of Water, which in that time had gone off in Vapour; tho' one could hardly perceive it ſmoke, and the Water were not ſenſibly warm. This Quantity in ſo ſhort a time ſeemed very conſiderable, being little leſs than 6 ounces in 24 hours, from ſo ſmall a Surface as a Circle of 8 Inches Diameter. To reduce this Experiment to an exact Calculus, and determine the thickneſs of the Skin of Water that had ſo evaporated, I aſſume the Experiment alledged by Dr. *Edward Bernard* to have been made in the *Oxford* Society, *viz.* That the Cube-foot Engliſh of Water weighs exactiy 76 Pounds *Troy*; this divided by 1728, the number of Inches in a Foot, will give $253\frac{1}{3}$ grains or $\frac{1}{2}$

ounce $13\frac{1}{3}$ grains for the weight of a Cube-inch of Water; wherefore the weight of 233 grains is $\frac{233}{253}$ or 35 Parts of 38 of a Cube-inch of Water. Now the Area of the Circle whoſe Diameter is $7\frac{9}{10}$ Inches, is 49 ſquare Inches; by which dividing the Quantity of Water evaporated, *viz.* $\frac{35}{38}$ of an Inch, the Quote $\frac{35}{1862}$ or $\frac{1}{53}$ ſhews that the thickneſs of the Water evaporated was the 53d part of an Inch; but we will ſuppoſe it only the 60th part, for the Facility of Calculation. If therefore Water as warm as the Air in Summer, exhales the thickneſs of a 60th part of an Inch in two hours from its whole Surface, in 12 hours it will exhale the $\frac{1}{10}$ of an Inch; which Quantity will be found abundantly ſufficient to ſerve for all the Rains, Springs, and Dews; and acount for the *Caſpian* Sea, being always at a ſtand, neither waſting nor overflowing; as likewiſe for the Current ſaid to ſet always in at the Streights of *Gibralter*, tho' thoſe Mediterranean Seas receive ſo many and ſo conſiderable Rivers.

To eſtimate the Quantity of Water ariſing in Vapours out of the Sea, I think I ought to conſider it only for the time the Sun is up, for that the Dews return in the night, as much if not more Vapours than are then emitted; and in Summer the Days being longer than 12 hours, this Exceſs is ballanced by the weaker Action of the Sun, eſpecially when riſing before the Water be warmed: So that if I allow $\frac{1}{10}$ of an Inch of the Surface of the Sea, to be raiſed *per diem* in Vapours, it may not be an improbable Conjecture.

Upon this Suppoſition, every 10 ſquare Inches of the Surface of the Water, yields in Vapour *per diem* a Cube-inch of Water; and each ſquare Foot half a Wine-pint; every Space of 4 Foot ſquare, a Gallon; a Mile ſquare, 6914 Tons; a ſquare Degree ſuppoſe of 69 Engliſh Miles, will evaporate 33 Millions of Tons: And if the Mediterranean be eſtimated at forty degrees long and four broad, allowances being made for the Places where it is broader, by thoſe where it is narrower (and I am ſure I gueſs at the leaſt) there will be 160 Square degrees of Sea; and conſequently, the whole Mediterranean muſt loſe in Vapour, in a Summer's day, at leaſt 5280 Millions of Tons. And this Quantity of Vapour, tho' very great, is as little as can be concluded from the Experiment produced: And yet there remains another Cauſe, which cannot be reduced to Rule, I mean the Winds, whereby the Surface of the Water is licked up ſome times faſter than it exhales by the heat of the Sun; as is well known to thoſe that have conſidered thoſe drying Winds which blow ſometimes.

To eſtimate the Quantity of Water, the Mediterranean Sea receives from the Rivers that fall into it; is a very hard Task, unleſs one had the Opportunity to meaſure their Chanels and Velocity; and therefore we can only do it by allowing more than enough; that is, by aſſuming theſe Rivers greater than in all probability they be, and then comparing the Quantity of Water voided by the *Thames*, with that of thoſe Rivers whoſe Waters we deſire to compute.

The Mediterranean receives theſe conſiderable Rivers; the *Iberus*, the *Rhone*, the *Tiber*, the *Po*, the *Danube*, the *Neiſter*, the *Boryſtenes*, the *Tanais*, and the *Nile*; all the reſt being of no great Note, and their Quantity of Water inconſiderable: Theſe nine Rivers, we will ſuppoſe each of them to bring down ten times as much Water as the River *Thames*; not that any of them is ſo great in reality, but to comprehend with them all the ſmall Rivulets that fall into the Sea, which otherwiſe I know not how to allow for.

To calculate the Water of the *Thames*, I aſſume that at *Kingſton* Bridge where the Flood never reaches, and the Water always runs down, the breadth of the Chanel is 100 Yards, and its Depth 3, it being reduced to an Equality (in both which Suppoſitions I am ſure I take with the moſt) hence the Profil of the Water in this Place is 300 ſquare Yards: This multiplied by 48 Miles (which I allow the Water to run in 24 hours, at 2 Miles an hour) or 84480 Yards, gives 25344000 Cubick-yards of Water to be evacuated every day; that is, 20300000 Tons *per diem*; and I doubt not, but in the exceſs of my Meaſures of the Chanel of the River, I have made more than ſufficient allowance for the Waters of the *Brent*, the *Wandel*, the *Lea*, and *Darwent*, which are all worth notice, that fall into the *Thames* below *Kingſton*.

Now if each of the aforeſaid 9 Rivers yield 10 times as much Water as the *Thames* doth, 'twill follow that each of them yields but 203 Millions of Ton *per diem*, and the whole 9 but 1827 Million of Tons in a day; which is but little more than $\frac{1}{3}$ of what is proved to be raiſed in Vapour out of the Mediterranean in 12 hours time. Now what becomes of this Vapour when rais'd, and how it comes to paſs that the Current always ſets in at the Mouth, of the Streights of *Gibralter*, ſhall immediately be ſhew'd: But firſt it is neceſſary to advertiſe the Reader, that in making the Experiment herein mention'd, the Water uſed: had been ſalted to the ſame degree as is the common Sea-water, by the Solution of about a 40th part of Salt.

HAving thus ſhew'd by Experiment the Quantity of Water raiſed in Vapour from the Surface the Sea in a Days time, which was ſo far approved of by ſome Honourable Members of this Society, that I received their Commands to proſecute theſe Enquiries; and particularly, in relation to the Method uſed by Nature, to return the ſaid Vapours again into the Sea; which is ſo juſtly performed, that in many hundred of Years we are ſufficiently aſſured that the Sea has not ſenſibly decreaſed by the loſs in Vapour; nor yet abounded by the immenſe Quantity of freſh it receives continually from the Rivers. To demonſtrate this Equilibre of Receipt and Expence in the whole Sea is a Task too hard for me to undertake, yet in obedience to thoſe whom I have the Honour to ſerve, I ſhall here offer, what to me has hitherto ſeem'd the moſt ſatisfactory Account of this grand *Phænomenon*: I have in another place attempted to explain the manner of the riſing of Vapour by Warmth, by ſhewing, that if an Atom of Water were expanded into a Shell or Bubble, ſo as to be ten times as big in Diameter as when it was Water; ſuch an Atom would become ſpecifically lighter than Air, and riſe ſo long as that *Flatus* or warm Spirit that firſt ſeparated it from the Maſs of Water, ſhall continue to diſtend it to the ſame Degree; and that warmth declining, and the Air growing cooler and with alſo ſpecifically lighter, the Vapours conſequently ſhall ſtop at a certain Region of the Air, or elſe deſcend, which may happen upon ſeveral accounts, as I ſhall by and by endeavour to make out; yet I undertake not that this is the only principal of the riſe of Vapours, and that there may not be a certain ſort of Matter whoſe *Conatus* may be contrary to that of Gravity; as is evident in Vegitation, wherein the Tendency of the Sprouts is directly upwards, or againſt the Perpendicular. But whatever is the true Cauſe, it is in Fact certain, that warmth does ſeparate the Particles of Water, and emit them with a greater and greater Velocity, as the heat is more and more intenſe; as is evident in the Steam of a boiling Cauldron, wherein likewiſe the Velocity of the aſcent of the Vapours does viſibly decreaſe till they diſappear, being diſperſed into and aſſimulated with the Ambient Air. Vapours being thus raiſed by warmth, let us for a firſt Suppoſition put, that the whole Surface of the Globe were all Water very deep, or rather that the whole Body of the Earth were Water, and that the Sun had his diurnal courſe about it: I take it, that it would follow, that the Air of it ſelf would imbibe a certain Quantity of aqueous Vapors, and retain them like Salts diſſolved in Water; that the Sun warming the Air, and raiſing a more plentiful Vapour from the Water in the day-time, the Air would ſuſtain a greater proportion of Vapour, as warm Water will hold more diſſolved Salts, which upon the abſence of the Sun in the Nights would be all again diſcharg'd in Dews, analogous to the Precipitation of Salts on the cooling of the Liquors; nor is it to be believed that in ſuch Caſe there would be any diverſity of Weather, other than periodically, every Year alike; the mixture of all terreſtrious, ſaline, heterogenious Vapours being taken away, which as they are variouſly compounded and brought by the Winds, ſeem to be the Cauſes of thoſe various Seaſons which we now find. In this caſe the Aiery Regions every where, at the ſame height, would be equally repleniſhed with the Proportion of Water it could contain, regard being only to be had to the different degree of warmth, from the nearneſs or diſtance of the Sun; and an eternal Eaſt-wind would blow all round the Globe, inclining only to the ſame ſide of the *Eaſt*, as the Latitude doth from the Equator; as is obſerved in the Ocean between the Tropicks.

Next let us ſuppoſe this Ocean interſperſed with wide and ſpacious Tracts of Land, with high Ridges of Mountains, ſuch as the *Pyrenean*, the *Alps*, the *Apennine*, the *Carpathian* in *Europe*, *Taurus Caucaſus Imaus*, and ſeveral others in *Aſia*; *Atlas* and the *Montes Lunæ*, with other unknown Ridges in *Africa*, whence came the *Nile*, the *Nigre*, and the *Zaire*: And in *America*, the *Andes* and the *Apalatean* Mountains; each of which far ſurpaſs the uſual height to which the Aqueous Vapours of themſelves aſcend, and on the tops of which the Air is ſo cold and rarified, as to retain but a ſmall part of thoſe Vapours that ſhall be brought thither by Winds. Thoſe Vapours therefore that are raiſed copiouſly in the Sea, and by the Wind, are carried over the low Land to thoſe Ridges of Mountains, are there compelled by the Stream of the Air to mount up with it to the tops of the Mountains, where the Water preſently precipitates, gleeting down by the Crannies of the Stone; and part of the Vapour entering into the Caverns of the Hills, the Water thereof gathers as in an Alembick into the Baſons of Stone it finds; which being once fill'd, all the overplus of Water that comes thither runs over by the loweſt place, and breaking out by the ſides of the Hills, forms ſingle *Springs.* Many of theſe running down by the Valleys or Guts between the ridges of the Hills, and coming to unite form little Rivulets, or Brooks: many of theſe again, meeting in one common Valley and gaining the plain Ground, being grown leſs rapid become a River: and many of theſe being united in one common Channel, make ſuch Streams as the *Rhine*, the *Rhone*, the *Danube*, which latter, one would hardly think the Collection of Water condenſed out of Vapour, unleſs we conſider how vaſt a Tract of Ground that River drains, and that it is the Sum of all thoſe Springs which break out on the South ſide of the *Carpathian* Mountains, and on the North ſide of the immenſe Ridge of the *Alps*, which is one continued Chain of Mountains from *Switzerland*, to the *Black-Sea.* And it may almoſt paſs for a Rule, that the magnitude of a River, or the quantity of Water it evacuates, is proportionable to the length and height of the Ridges from whence its Fountains ariſe. Now this Theory of *Springs* is not a bare *Hypotheſis*, but founded on Experience, which it was my luck to gain in my abode at St. *Helena*, where in the Night time, on the tops of the Hills, about 800 Yards above the Sea, there was ſo ſtrange a condenſation, or rather precipitation of the Vapours, that it was a great Impediment to my Cœleſtial Obſervations; for in the clear Sky, the Dew would fall ſo faſt, as to cover each half quarter of an Hour, my Glaſſes with little drops, ſo that it I was neceſſitated to wipe them ſo often, and my Paper on which I wrote my Obſervations would immediately be ſo wet with Dew, that it would not bear Ink: By which it may be ſuppos'd how faſt the Water gathers in thoſe mighty high Ridges I but now nam'd.

Thus is one part of the Vapours blown upon the Land return'd by the Rivers into the Sea, from whence they came; another part by the cool of the Night falls in Dews, or elſe in Rains, again into the Sea before it reaches the Land, which is by much the greateſt part of the whole Vapours, becauſe of the great extent of the Ocean, which the motion of the Winds does not traverſe in a very long ſpace of Time; and this is the Reaſon why the Rivers do not return ſo much into the *Mediterranean*, as is extracted into Vapour. A third part falls on the Low-Lands, and is the *Pabulum* of Plants, where yet it does not reſt, but is again exhaled in Vapour by the action of the Sun, and is either carried by the Winds to the Sea to fall in Rain or Dew there, or elſe to the Mountains to be there turn'd into Springs; and tho' this does not immediately come to paſs, yet after ſeveral Viciſſitudes of riſing in Vapour, and falling in Rain or Dews, each Particle of the Water is at length return'd to the Sea from whence it came. Add to this, that the Rain-waters after the Earth is fully ſated with moiſture, does, by the Vallies or lower parts of the Earth, find its way into the Rivers, and ſo is compendiouſly ſent back to the Sea. After this manner is the Circulation perform'd, and I doubt not but this Hypotheſis is more reaſonable than that of thoſe who derive all Springs from the Rain-waters, which yet are perpetual and without diminution, even when no Rain falls for a long ſpace of time; or that derive them from a Filtration or Pecolation of the Sea-waters, tho' certain imaginary Tubes or Paſſages within the Earth wherein they loſe their Saltneſs. This, beſides many others, labouring under this principal Abſurdity, that the greateſt Rivers have their moſt copious Fountains fartheſt from the Sea, and whether ſo great quantities of freſh Water cannot reaſonably be deriv'd any other way than in Vapour. This, if we may allow final Cauſes, ſeems to be the deſign of the Hills that their Ridges being plac'd thro' the midſt of the Continents, might ſerve, as it were, for Alembicks to diſtil freſh Water for the uſe of Man and Beaſt, and their heights to give a deſcent to thoſe Streams to run gently, like ſo many Veins of the *Macrocoſm* to be the more benificial to the Creation. If the difference between Rain and Dew, and the cauſe why ſometimes 'tis Cloudy, at other times Serene, be inquir'd, I can offer nothing like a proper Solution thereof, only with ſubmiſſion to propoſe Conjectures, which are the beſt I can find, *viz.* That the Air being heaped up by the meeting of two contrary Winds, when the *Mercury* is high, the Vapours are the better ſuſtain'd and kept from Co-agulating or Condenſing into Drops, whereby Clouds are not ſo eaſily generated; and in the Night the Vapours fall down ſingle, as they aroſe in imperceptible Atoms of Water: Whereas, when the *Mercury* is low and the Air rarified by the Exhauſtion thereof, by two contrary Winds blowing from the place; the Atoms of Air keep the Vapours not ſo well ſeparated, and they Coaleſce into viſible Drops in the Clouds, and from thence are eaſily drawn into greater Drops of Rain; to which 'tis poſſible and not improbable, that ſome ſort of Saline or Angular Particles of Terreſtrial Vapour being immix'd with the Aqueous, which I take to be Bubbles, may cut or break their Skins or Coats, and ſo contribute to their more ſpeedy Condenſation into Rain.

The True Theory of the Tides, extracted from that admired Treatiſe of Mr. Iſaac Newton, *Intituled*, Philoſophiæ Naturalis Principia Mathematica; *being a Diſcourſe preſented with that Book to the late King* James, *by Mr.* Edmund Halley.

IT may, perhaps, ſeem ſtrange, that this Paper, being no other than a partile Account of a Book long ſince publiſhed, ſhould now appear here; but the Deſire of ſeveral honourable Perſons, which could not be withſtood have obliged us to inſert it here. for the ſake of ſuch, who being leſs knowing in Mathematical Matters; and therefore not daring to adventure on the Author himſelf, are notwithſtanding, very curious to be informed of the Cauſes of Things; particularly of ſo general and extraordinary Phænomena, *as are thoſe of the Tides. Now this Paper having been drawn up for the late King* James's *Uſe, (in whoſe Reign the Book was publiſhed) and having given good Satisfaction to thoſe that got Copies of it; it is hoped the Savans of the higher Form will indulge us this Liberty we take to gratiſie their Inferiours in point of Science; and not be offended, that we here inſiſt more largely upon Mr.* Newton's Theory of the Tides, *which, how plain and eaſie ſoever we find, is very little underſtood by the common Reader.*

THE ſole Principle upon which this Author proceeds to explain moſt of the great and ſurprizing Appearances of Nature, is no other then that of *Gravity*, whereby in the Earth all Bodies have a tendency towards its Centre; as is moſt evident: and from undoubted Arguments its proved, that there is ſuch a Gravitation towards the Centre of the Sun, Moon, and all the Planets.

From this Principle, as a neceſſary Conſequence, follows the Sphærical Figure of the Earth and Sea, and of all the other Cæleſtial Bodies: and tho' the tenacity and firmneſs of the Solid Parts, ſupport the Inequalities of the Land above the Level; yet the Fluids, preſſing equally and eaſily yielding to each other, ſoon reſtore the *Æquilibrium*, if diſturbed, and maintain the exact Figure of the Globe.

Now this force of Deſcent of Bodies towards the Center, is not in all places alike, but is ſtill leſs and leſs, as the diſtance from the Center encreaſes: and in this Book it is demonſtrated, that this Force decreaſes as the Square of the diſtance increaſes; that is, the weight of Bodies and the force of their Fall is leſs, in parts more removed from the Center, in the proportion of the Squares of the Diſtance. So as for Example, a Ton weight on the Surface of the Earth, if it were raiſed to the height of 4000 Miles, which I ſuppoſe the Semidiameter of the Earth, would weigh but $\frac{1}{4}$ of a Ton, or 5 Hundred weight: If to 12000 Miles, or 3 Semidiameters from the Surface, that is 4 from the Center, it would weigh but $\frac{1}{16}$ part of the Weight on the Surface, or a Hundred and Quarter: So that it would be as eaſie for the

Strength of a Man at that height to carry a Ton weight, as here on the Surface a $100\frac{1}{4}$. And in the ſame Proportion does the Velocities of the fall of Bodies decreaſe: For whereas on the Surface of the Earth all things fall 16 Foot in a ſecond, at one Semidiameter above, this fall is but four Foot; and at three Semidiameters, or four from the Centre, it is but $\frac{1}{16}$ of the Fall at the Surface, or but one Foot in a ſecond: And at greater Diſtances both Weight and Fall become very ſmall, but yet at all given Diſtances is ſtill ſome thing, tho' the Effect become inſenſible. At the diſtance of the Moon (which I will ſuppoſe 60 Semidiameters of the the Earth) 3600 Pounds weigh but one Pound, and the fall of Bodies is but $\frac{1}{3600}$ of a Foot in a ſecond, or 16 Foot in a Minute; that is, a Body ſo far off deſcends in a Minute no more than the ſame at the Surface of the Earth would do in a Second of Time.

As was ſaid before, the ſame force decreaſing after the ſame manner is evidently found in the Sun, Moon, and all the Planets; but more eſpecially in the Sun, whoſe Force is prodigious; becoming ſenſible even in the immenſe diſtance of *Saturn:* This gives room to ſuſpect, that the force of Gravity is in the Cœleſtial Globes proportional to the quantity of Matter in each of them: And the Sun being at leaſt ten Thouſand times as big as the Earth, its Gravitation or attracting Force, is found to be at leaſt ten Thouſand times as much as that of the Earth, acting on Bodies at the ſame diſtance.

This Law of the decreaſe of Gravity being demonſtratively proved, and put paſt contradiction; the Author with great Sagacity, inquires into the neceſſary Conſequences of this

Suppoſition; whereby he finds the genuine Cauſe of the ſeveral Appearances in the Theory of the Moon and Planets, and diſcovers the hitherto unknown Laws of the Motion of Comets, and of the Ebbing and flowing of the Sea. Each of which are Subjects that have hitherto taken up much larger Volumes; but Truth being uniform, and always the ſame, it is admirable to obſerve how eaſily we are enabled to make out very abſtruſe *and difficult Matters*, when once true and genuine Principles are obtained: And on the other hand it may be wondred, that, notwithſtanding the great facility of truth, and the perplexity and nonconſequences that always attend erroneous Suppoſitions, theſe great Diſcoveries ſhould have eſcaped the acute Diſquiſitions of the beſt Philoſophical Heads of all paſt Ages, and be reſerv'd to theſe our Times. But that wonder will ſoon ceaſe, if it be conſider'd how great improvements Geometry has receiv'd in our Memory, and particularly from the profound Diſcoveries of our incomparable Author.

The Theory of the Motion of the primary *Planets* is here ſhewn to be nothing elſe, but the contemplation of the Curve Lines which Bodies caſt with a given Velocity, in a given Direction and at the ſame time drawn towards the Sun by its gravitating Power, would deſcribe. Or, which is all one, that the Orbs of the Planets are ſuch Curve Lines as a Shot from a Gun deſcribes in the Air, being caſt according to the direction of the Piece, but bent in a crooked Line by the ſupervening Tendency towards the Earths Centre: And the Planets being ſuppoſed to be projected with a given Force, and attracted towards the Sun, after the aforeſaid manner, are here proved to deſcribe ſuch Figures, as anſwer punctually to all that the Induſtry of this and the laſt Age has obſerv'd in the Planetary Motions. So that it appears, that there is no need of ſolid Orbs and Intelligences, as the Antients imagin'd, nor yet of *Vortices* or Whirlpools of the Celeſtial Matter, as *Des Cartes* ſuppoſes; but the whole Affair is ſimply and mechanically performed, upon the ſole Suppoſition of a Gravitation towards the Sun; which cannot be denied.

The Motion of *Comets* is here ſhewn to be compounded of the ſame Elements, and not to differ from Planets, but in their greater ſwiftneſs, whereby overpowering the Gravity that ſhould hold them to the Sun, as it doth the Planets, they flie off again, and diſtance themſelves from the Sun and Earth, ſo that they ſoon are out of our ſight. And the imperfect Accounts and Obſervations Antiquity has left us, are not ſufficient to determine whether the ſame Comet ever return again. But this Author has ſhewn how Geometrically to determine the Orb of a Comet from Obſervations, and to find his diſtance from the Earth and Sun, which was never before done.

The third thing here done is the Theory of the Moon, all the Inequalities of whoſe Motion are proved to ariſe from the ſame Principles, only here the effect of two Centers operating on, or attracting a projected Body comes to be conſidered; for the Moon, tho principally attracted by the Earth, and moving round it, does together with the Earth, move round the Sun once a Year, and is according as ſhe is, nearer or farther from the Sun, drawn by him more or leſs than the Center of the Earth, about which ſhe moves; whence ariſe ſeveral Irregularities in her Motion, of all which, the Author in this Book, with no leſs Subtility than Induſtry, has given a full account. And tho' by reaſon of the great Complication of the Problem, he has not yet been able to make it purely Geometrical, 'tis to be hoped, that in ſome farther Eſſay he may ſurmount the difficulty: And having perfected the Theory of the Moon, the long deſir'd diſcovery of the Longitude (which at Sea is only practicable this way) may at length be brought to light, to the great Honour of your Majeſty and Advantage of your Subjects.

All the ſurprizing Phænomena of the Flux and Reflux of the Sea, are in like manner ſhewn to proceed from the ſame Principle; which I deſign more largely to inſiſt on, ſince the matter of Fact is in this caſe much better known to your Majeſty than in the foregoing.

If the Earth were alone, that is to ſay, not affected by the Actions of the Sun and Moon, it is not to be doubted, but the Ocean, being equally preſs'd by the force of Gravity towards the Center, would continue in a perfect ſtagnation, always at the ſame height, without either Ebbing or Flowing; but it being here demonſtrated, that the Sun and Moon have a like Principle of Gravitation towards their Centers, and that the Earth is within the Activity of their Attractions, it will plainly follow, that the Equality of the preſſure of Gravity towards the Center will thereby be diſturb'd; and tho' the ſmallneſs of theſe Forces, in reſpect of the Gravitation towards the Earths Center, renders them altogether imperceptible by any Experiments we can deviſe, yet the Ocean being fluid and yeilding to the leaſt force, by its riſing ſhews where it is leſs preſt, and where it is more preſt by its ſinking.

Now if we ſuppoſe the force of the Moons Attraction to decreaſe as the Square of the Diſtance from its Center increaſes (as in the Earth and other Celeſtial Bodies) we ſhall find, that where the Moon is perpendicularly either above or below the Horizon, either in Zenith or Nadir, there the force of Gravity is moſt of all diminiſhed, and conſequently that there the Ocean muſt neceſſarily ſwell by the coming in of the Water from thoſe parts where the Preſſure is greateſt, *viz.* in thoſe places where the Moon is near the Horizon: But that this may be the better underſtood, I thought it needful to add the following Figure, (*Vide Fig.* 1. *Plate* 1.) where *M* is the Moon, *E* the Earth, *C* its Center, and *Z* the place where the Moon is in the Zenith, *N* where in the Nadir.

Now by the Hypotheſis it is evident, that the Water in *Z*, being nearer, is more drawn by the Moon, than the Center of the Earth *C*, and that again more than the Water in *N*, wherefore the Water in *Z* hath a tendency towards the Moon, contrary to that of Gravity, being equal to the exceſs of the Gravitation in *Z*, above that in *C*: And in the other caſe, the Water in *N*, tending leſs towards the Moon than the Center *C*, will be leſs preſſed, by as much as is the difference of the Gravitations towards the Moon in *C* and *N*. This rightly underſtood, it follows plainly, that the Sea, which otherwiſe would be Spherical, uppon the Preſſure of the Moon, muſt form it ſelf into a Spheroidal or Oval Figure, whoſe longeſt Diameter is where the Moon is vertical, and ſhorteſt where ſhe is in the Horizon; and that the Moon ſhifting her Poſition as ſhe turns round the Earth once a Day, this Oval of Water ſhifts with her, occaſioning thereby the two Floods and Ebbs obſervable in each 25 Hours.

And this may ſuffice as to the general Cauſe of the Tides; it remains now to ſhew how naturally this motion accounts for all the Particulars that have been obſerv'd about them; ſo that there can be no room left to doubt, but that this is the true cauſe thereof.

The Spring Tides upon the New and Full Moons, and Neap Tides on the Quarters, are occaſion'd by the attractive Force of the Sun in the New and Full, conſpiring with the Attraction of the Moon, and producing a Tide by their united Forces: Whereas in the Quarters, the Sun raiſes the Water where the Moon depreſſes it, and the contrary; ſo as the Tides are made only by the difference of their Attractions. That the force of the Sun is no greater in this caſe, proceeds from the very ſmall Proportion the Semidiameter of the Earth bears to the vaſt diſtance of the Sun.

It it alſo obſerv'd, that *cæteris paribus*, the Æquinoctial Spring Tides in *March* and *September*, or near them, are the Higheſt, and the Neap Tides the loweſt; which proceeds from the greater Agitations of the Waters, when the fluid *Spheroid* revolves about a great Circle of the Earth, than when it turns about in a leſſer Circle; it being plain, that if the Moon were conſtituted in the Pole and there ſtood, that the *Spheroid* would have a fixt Poſition, and that it would be always high Water under the Poles, and low Water every where under the Æquinoctial: And therefore the nearer the Moon approaches the Poles, the leſs is the agitation of the Ocean, which is of all the greateſt, when the Moon is in the Æquinoctial, or fartheſt diſtant from the Poles. Whence the Sun and Moon, being either conjoined or oppoſite in the Æquinoctial, produce the greateſt Spring Tides; and the ſubſequent Neap Tides, being produc'd by the Tropical Moon in the Quarters, are always the leaſt Tides; whereas in *June* and *December*, the Spring Tides are made by the Tropical Sun and Moon, and therefore leſs vigorous; and the Neap Tides by the Æquinoctial Moon, which therefore are the ſtronger: Hence it happens, that the difference between the Spring and Neap Tides in theſe Months, is much leſs conſiderable than in *March* and *September*. And the reaſon why the very higheſt Spring Tides are found to be rather before the Vernal and after the Autumnal Equinox, *viz.* in *February* and *October*, than priciſely upon them, is, becauſe the Sun is nearer the Earth in the Winter Months, and ſo comes to have a greater effect in producing the Tides.

Hitherto we have conſider'd ſuch Affections of the Tides as are Univerſal, without relation to particular Caſes; what follows from the differing Latitudes of places, will be eaſily underſtood by the following Fig. (*Vide Fig.* 2. *Plate* 1.) p. 96-

Let *A p Æ P* be the Earth cover'd over with very deep Waters, *C* its Center, *P*, *p*, its Poles, *A E* the Æquinoctial, *F f* the parallel of Latitude of a Place, *D d* another Parallel at equal diſtance on the other ſide of the Æquinoctial, *H h* the two Points where the Moon is vertical, and let *K k* be the great Circle, wherein the Moon appears Horizontal. It is evident, that a Spheriod deſcrib'd upon *H h*, and and *K k* ſhall nearly repreſent the Figure of the Sea, and *Cf*, *CD*, *CF*, *C d* ſhall be the hights of the Sea in the places *f*, *D*, *F*, *d*, in all which it is High-water: And ſeeing that in twelve Hours time, by the diurnal Rotation of the Earth, the Point *F* is transferr'd to *f*, and *d* to *D*: The hight of the Sea *CF* will be that of the High-water when the Moon is preſent, and *Cf* that of the other High-water, when the Moon is under the Earth: Which in the caſe of this Figure is leſs than the former *CF*. And in the oppoſite Parallel *D d* the contrary happens. The Riſing of the Water being always alternately greater and leſs in each place, when it is produc'd by the Moon declining ſenſibly from the Æquinoctial; that being the greateſt of the two High-waters in each diurnal Revolution of the Moon, wherein ſhe approaches neareſt either to the Zenith or Nadir of the place: Whence it is that the Moon in the Northern Signs, in this part of the World, makes the greateſt Tides when above the Earth, and in Southern Signs, when under the Earth; the Effect being always the greateſt where the Moon is fartheſt from the Horizon, either above or below it. And this alternate increaſe and decreaſe of the Tides has been obſerv'd to hold true on the Coaſt of *England*, at *Briſtol* by Capt. *Sturmy*, and at *Plymouth* by Mr. *Colepreſſe*.

But the motions hitherto mention'd are ſomewhat alter'd by the Libration of the Water, whereby, tho' the Action of the *Luminaries*

ries ſhould ceaſe, the Flux and Reflux of the Sea would for ſome time continue: This Conſervation of the impreſs'd Motion diminiſhes the differences that otherwiſe would be between two conſequent Tides, and is the reaſon why the higheſt Spring-Tides are not preciſely on the New and Full Moons, nor the Neaps on the Quarters; but generally they are the third Tides after them, and ſometimes later.

All theſe things would regularly come to paſs, if the whole Earth were cover'd with Sea very deep; but by reaſon of the ſhoalneſs of ſome places, and the narrowneſs of the Streights, by which the Tides are in many caſes propagated, there ariſes a great diverſity in the Effect, and not to be accounted for, without an exact Knowledge of all the Circumſtances of the Places, as of the Poſition of the Land, and the Breadth and Depth of the Channels by which the Tide flows; for a very ſlow and imperceptible motion of the whole Body of the Water, where it is (for example) 2 Miles deep, will ſuffice to raiſe its Surface 10 or 12 Feet in a Tides time; whereas, if the ſame quantity of Water were to be convey'd upon a Channel of 40 Fathoms deep, it would require a very great Stream to effect it, in ſo large Inlets as are the Channel of *England* and the *German* Ocean; whence the Tide is found to ſet ſtrongeſt in thoſe places where the Sea grows narroweſt; the ſame quantity of Water being to paſs through a ſmaller Paſſage: This is moſt evident in the *Streights*, between *Portland* and *Cape de Hague* in *Normandy*, where the Tide runs like a Sluce; and would be yet more between *Dover* and *Calis*, if the Tide coming about

bout the Iſland from the North did not check it. And this force being once impreſs'd upon the Water, continues to carry it above the level of the ordinary height in the Ocean, particularly where the Water meets a direct Obſtacle, as it is at St. *Malo*'s; and where it enters into a long Channel, which running far into the Land, grows very ſtreight at its Extremity; as it is in the *Severn-Sea* at *Chepſtow* and *Briſtol.*

This ſhoalneſs of the Sea and the intercurrent Continents are the reaſon, that in the open Ocean the time of High-water is not at the Moons appulſe to the Meridian, but always ſome Hours after it; as it is obſerv'd upon all the Weſt-Coaſt of *Europe* and *Africa*, from *Ireland* to the *Cape of Good-Hope:* In all which a S. W. Moon makes High-water, and the ſame is reported to be on the Weſt ſide of *America.* But it would be endleſs to account all the particular Solutions, which are eaſie Corollaries of this *Hypotheſis*; as why the *Lakes*, ſuch as the *Caſpian Sea*, and *Mediterranian Seas*, ſuch as the *Black Sea*, the *Streights* and *Baltick*, have no ſenſible Tides: For *Lakes* having no Communication with the Ocean, can neither increaſe nor diminiſh their Water, whereby to riſe and fall; and Seas that communicate by ſuch narrow Inlets, and are of ſo immenſe an Extent, cannot in a few Hours time receive or empty Water enough to raiſe or ſink their Surface any thing ſenſibly.

Laſtly, to demonſtrate the excellency of this Doctrine, the Example of the Tides in the Port of *Tunking* in *China*, which are ſo extraordinary, and differing from all others we have yet heard of, may ſuffice. In this Port there is but one Flood and Ebb in 24 Hours; and twice in each Month, *viz.* when the Moon is near the Æquinoctial there is no Tide at all, but the Water is ſtagnant; but with the Moons declination there begins a Tide, which is greateſt when ſhe is in the Tropical Signs: Only with this difference, that when the Moon is to the Northward of the Æquinoctial, it Flows when ſhe is above the Earth, and Ebbs when ſhe is under, ſo as to make High-water at Moons-ſetting, and Low-water at Moons-riſing: But on the contrary, the Moon being to the Southward, makes High-water at riſing and Low-water at ſetting; it Ebbing all the time ſhe is above the Horizon. As may be ſeen more at large in the *Philoſophical Tranſaction*, Numb. 162.

The Cauſe of this odd Appearance is propos'd by Mr. *Newton*, to be from the concurrence of two Tides; the one propagated in ſix Hours out of the great *South-Sea* along the Coaſt of *China*; the other out of the *Indian-Sea*, from between the Iſlands in twelve Hours, along the Coaſt of *Malacca* and *Cambodia*. The one of theſe Tides, being produc'd in North-Latitude, is, as has been ſaid, greater, when the Moon being to the North of the Equator is above the Earth, and leſs when ſhe is under the Earth. The other of them, which is propagated from the *Indian-Sea*, being raiſed in South-Latitude, is greater when the Moon declining to the South, is above the Earth, and leſs when ſhe is under the Earth: So that of theſe Tides alternately greater and leſſer, there comes always ſucceſſively two of the greater and two of the leſſer together every day; and the High-water falls always between the times of the arrival of the two greater Floods; and the Low-water between the arrival of the two leſſer Floods. And the Moon coming to the Æquinoctial, and the alternate Floods becoming equal, the Tide ceaſes and the Water ſtagnates: But when ſhe has paſs'd to the other ſide of the Equator, thoſe Floods which in the former Order were the leaſt, now becoming the greateſt, that That before was the time of High-water now becomes the Low-water, and the Converſe. So that the whole appearance of theſe ſtrange Tides, is without any forcing naturally deduc'd from theſe Principles, and is a great Argument of the certainty of the whole *Theory*.

A Theory of the Variation *of the* Magnetical Compaſs, *by Mr.* Ed. Halley *Fellow of the R. S.*

THE variation of the Compaſs (by which I mean the deflection of the Magnetical Needle from the true Meridian) is of that great concernment in the Art of Navigation, that the neglect thereof, does little leſs than render uſeleſs one of the nobleſt Inventions Mankind ever yet attained to. And for this cauſe all Ships of Conſequence (eſpecially thoſe bound beyond the Equator) carry with them Inſtruments on purpoſe to obſerve this variation: That ſo the Courſe ſtear'd by the Compaſs, may be reduc'd to the true Courſe in reſpect of the Meridian.

Now altho' the great utility that a perfect knowledge of the Theory of the Magnetical Direction would afford to Mankind in general, and eſpecially to thoſe concern'd in Sea Affairs, ſeems as ſufficient incitement to all Philoſophical and Mathematical Heads, to take under ſerious Conſideration the ſeveral *Phænomena*, and to endeavour to reconcile them by ſome general Rule: Yet ſo it is; that almoſt all the Authors, from whom a Diſcourſe of this kind ought to have been expected, paſs by in ſilence the difficulties they here encounter. And thoſe that mention this variation: By affirming it to proceed from Cauſes altogether uncertain (as are the caſual lying of Iron Mines and Loadſtones in the Earth) put a ſtop to all further Contemplation; and give diſcouragement to thoſe that would otherwiſe uudertake this Enquiry. 'Tis true, that not long ſince one Mr. *Bond*, an old Teacher of Navigation, put forth a ſmall Treatiſe wherein he pretends to calculate the variation: But he limits his Hypotheſis to the City of *London*, affirming himſelf (as he had a great deal of reaſon) that the ſame *Calculus* is not ſufficient for other places; whereby it appears that this Rule is far ſhort of the ſo much deſir'd general one.

Now although (through want of ſufficient Obſervations and ſome other difficulties which I ſhall anon ſhew) I cannot pretend perfectly to eſtabliſh the Numbers and Rules of a *Calculus* which ſhall preciſely anſwer to the variations of all parts of the World: Yet I ſuppoſe it will not be unacceptable to the curious to propoſe ſomething of a light into this abſtruſe Myſtery; which, if no other, may have this good effect, to ſtir up the Philoſophical *Genii* of the Age to apply themſelves more attentively to this uſeful ſpeculation. But before I proceed, 'twill be neceſſary to lay down the Grounds upon which I raiſe my Concluſions; and at once to give a Synopſis of thoſe variations which I have reaſon to look upon as ſure, being moſtly the Obſervations of Perſons of good Skill and Integrity.

A
TABLE
OF
VARIATIONS.

Names of Places.	*Longitude from* Lon.	*Latitude.*	*Anno Dom.*	*Variation Obſerv'd.*
	d m	*d m*		*d m*
London	0 0	51 32 N	1580	11 15 E
			1622	6 0 E
			1634	4 5 E
			1672	2 30 W
			1683	4 30 W
Paris	2. 25 E	48. 51 N	1640	3 00 E
			1666	0 0
			1681	2 30 W
Uraniburg	13. 0 E	55. 54 N	1672	2 35 W.
Copenhagen	12. 53 E	55. 41 N	1649	1 30 E
			1672	3 35 W
Dantzick	19. 0 E	54. 23 N	1679	7 00 W
Mompelier	4. 0 E	43. 37 N	1674	1 10 W
Breſt	4. 25 W	48. 23 N	1680	1 45 W.
Rome	13. 0 E	41. 50 N	1681	5 0 W
Bayonne	1. 20 W	43. 30 N	1680	1 20 W
Hudſon's Bay	79. 40 W	51 00 N	1668	19 15 W
In *Hud.* Straights	57. 00 W	61 00 N	1668	29 30 W
In *Baffins* Bay at Sir *Thomas Smiths* Sound	80. 00 W	78 00 N	1616	57 00 W

Names

Names of Places.	*Longitude.*			*Latitude.*			*Anno Dom.*	*Variation*		
	d	*m*		*d*	*m*			*d*	*m*	
At Sea	50	0	W	38	40	N	1682	7	30	W
At Sea	31	30	W	43	50	N	1682	5	30	W
At Sea	42	0	W	21	0	N	1678	0	40	E
Cape St. *Aug.* of *Brazile*	35	30	W	8	0	S	1670	5	30	E
Cape Frio	41	10	W	22	40	S	1670	12	10	E
At Sea off of the Mou. of the River of *Plate*	53	00	W	39	30	S	1670	20	30	E
At the Eaſt Entrance of *Magellan* Straits	68	00	W	52	30	S	1670	17	00	E
At the W. Entrance of the *Magellan* Straits	75	00	W	53	00	S	1670	14	10	E
Baldivia	73	00	W	40	00	S	1670	8	10	E
At Cape d' *Agulbas*	16	30	E	34	50	S	1622 1675	2 8	00 00	W W
At Sea	1	0	E	34	30	S	1675	0	0	
At Sea	20	0	W	34	0	S	1675	10	30	E
At Sea	32	0	W	24	0	S	1675	10	30	E
At St. *Helena*	6	30	W	16	0	S	1677	0	40	E
At *Aſcenſion*	14	30	W	7	50	S	1678	1	00	E
At *Johanna*	44	00	E	12	15	S	1675	19	30	W
At *Monbaſa*	40	00	E	4	00	S	1675	16	00	W
At *Zocatra*	56	00	E	12	30	N	1674	17	00	W
At *Aden*, at the M. of the *Red-Sea*	47	30	E	13	00	N	1674	15	00	W
At *Diego Roiz*	61	0	E	20	0	S	1676	20	30	W
At Sea	64	30	E	0	0		1676	15	30	W
At Sea	55	0	E	27	0	S	1676	24	00	W
At *Bombay*	72	30	E	19	0	N	1676	12	00	W
At Cape *Comorin*	76	00	E	8	15	N	1680	8	48	W
At *Ballaſore*	87	00	E	21	30	N	1680	8	20	W
At Fort St. *George*	80	00	E	13	15	N	1680	8	10	W
At the W. point of *Java*.	104	0	E	6	40	S	1676	3	10	W

At

At Sea	58 00 E	39 0 S	1677	27 30 W
At the Iſle of St. *Paul*	72 0 E	38 0 S	1677	23 30 W
At *Van Diemens* Land	142 0 E	42 25 S	1642	0 0
At new *Zealand*	170 0 E	40 50 S	1642	9 0 E
At Three Kings Iſle in New *Zeland*	169 30 E	34 35 S	1642	8 40 E
At the Iſle *Rotterdam* in the South Sea	184 00 E	20 15 S	1642	6 20 E
on the Coaſt of *N.Guniea*	149 00 E	4 30 S	1643	8 45 E
at the W. p. of *N.Guniea*	126 00 E	0 26 S	1643	5 30 E

Tho' I could wiſh we could obtain from the *Spaniards* what Variations they find in their Voyages from the *Manilhas* towards *Acapulco*, thorough the North part of the South Sea; as likewiſe what it is at *Japan*, from the *Dutch*: Yet (conſidering the number of theſe Obſervations I have collected, and that they are made in parts of the World ſo remote from *Europe*, and from one another) I ſuppoſe that the Theory that anſwers theſe will ſcarce fail in thoſe Regions from whence we have as yet no account. But firſt we muſt make ſome remarkes upon the foregoing Table: And, Firſt,

That in all *Europe* the variation at this time is *Weſt*, and more in the Eaſtern Parts thereof than the Weſtern: As likewiſe that it ſeems throughout to be upon the increaſe that way.

Secondly, That on the Coaſt of *America*, about *Virginia*, *New-England* and *New-Found-Land*, the variation is likewiſe Weſterly; and that it increaſes all the way as you go Northerly along the Coaſt ſo as to be above 20 Degrees at *New-found-Land*, nearly 30 gr. in *Hudſons Straits*, and not leſs than 57 Degrees in

Baffins Bay; alſo, that as you Sail Eaſtward from this Coaſt the variation diminiſhes. From theſe two it is a Legitimate Corallary: That *Somewhere between* Europe, *and the North part of* America, *there ought to be an Eaſterly Variation, or at leaſt no Weſterly.* And ſo I conjecture it is about the Eaſtermoſt of the *Tercera Iſlands.*

Thirdly, That on the Coaſt of *Braſile* there is Eaſt variation, which increaſes very notably as you go to the Southward ſo as to be 12 Degrees at *Cape Frio*, and over againſt the River of *Plate* 20 ½ Degrees: And from thence Sailing Southweſterly to the Straits of *Magellan* it decreaſes 17 Degrees, and at the Weſt Entrance but 14 Degrees.

Fourthly, That at the Eaſtward of *Braſile* properly ſo called, this Eaſterly variation decreaſes, ſo as to be very little at St. *Helena* and *Aſcenſion*, and to be quite gone and the Compaſs Point true about 18 Degrees of Longitude Weſt from the Cape of *Good-hope*.

Fifthly, That to the Eaſtward of the aforeſaid Places a Weſtward variation begins, which Reigns in the whole *Indian* Sea, and ariſes to no leſs than Eighteen Degrees under the Equator itſelf, about the Meridian of the Northern part of *Madagaſcar*; and near the ſame Meridian but in 39. Degrees South Latitude it is found full 27 ½ Degrees: From thence Eaſterly the Weſt variation decreaſes, ſo as to be little more than eight Degrees at *Cape Comorin*, and than three Degrees upon the Coaſt of *Java*; and to be quite extinct about the *Molucca Iſlands*, as alſo a little to the Weſtwards of *Van*

Diemens Land found out by the *Dutch* in 1642.

Sixthly, That to the Eaſtward of the *Molucca*'s and *Van Diemens* Land in South Latitude there ariſes another Eaſterly Variation, which ſeems not ſo great as the former, nor of ſo large extent; for that at the Iſland *Rotterdam* it is ſenſibly leſs than upon the Eaſt Coaſt of *New Guinea*; and, at the rate it decreaſes, it may well be ſuppos'd, that about 20 Degrees farther Eaſt or 225 Degrees Eaſt Longitude from *London*, in the Latitude of 20 Degrees South, a Weſterly Variation begins.

Seventhly, That the variations obſerv'd by the Honourable Sir *John Norborough* at *Baldivia* and at the Weſt Entrance of the *Straights* of *Magellan* do plainly ſhew, that That Eaſt variation, noted in our third Remark, is decreaſing apace; and that it cannot reaſonably extend many Degrees into the South Sea from the Coaſt of *Peru* and *Chili*, leaving room for a ſmall Weſterly variation, in that Tract of the unknown World that lies in the mid-Way between *Chili* and *New-Zealand*, and between *Hounds-Iſland* and *Peru*.

Eighthly, That in Sailing North-Weſt from St. *Helena* by *Aſcenſion* as far as the Equator the variation continues very ſmall Eaſt, and as it were conſtantly the ſame: So that in this part of the World the Courſe, wherein there is no variation, is evidently no Meridian, but rather North-Weſt.

Ninthly, That the Entrance of *Hudſon*'s *Straights* and the Mouth of the River of *Plate* being nearly under the ſame Meridian, at the one place the Needle varies 29½ Degrees to the *Weſt*; at the other 20½ Degrees to the *Eaſt*. This plainly demonſtrates the impoſſibility of reconciling theſe variations by the Theory of *Bond*; *which is by two Magnetical Poles and an Axis, inclined to the Axis of the Earth*; from whence it would follow, That *under the ſame Meridian the Variation ſhould be in all places the ſame way*.

These things being premiſed may ſerve as a ſure Foundation to raiſe the ſuperſtructure of a Theory upon. But firſt it would not be amiſs to ſhew hereby the miſtake of *Gilbert* and *Des Cartes*: The firſt whereof ſuppoſes; that *the Earth itſelf being in all its parts Magnetical, aud the Water not; wheresoever the Land is, thither alſo ſhould the Needle turn, as to the greater quantity of Magnetical Matter.* But this in many inſtances is not true; but moſt remarkably upon the Coaſt of *Braſile*, where the Needle is ſo far from being attracted by the Land, that it turns the quite contrary way, leaving the Meridian to lye N B E, which is juſt along the Coaſt. As to the Poſition of *Des Cartes, that the Iron and Loadſtones hid in the Bowels of the Earth and the Bottom of the Sea may be the Cauſes that the Needle varies*; if we conſider for how great a part of the Earths Surface, *ex gr.* in the whole *Indian* Sea, the Needle declines the ſame way, and that regularly, 'Twill follow that the attracting Subſtance that occaſions it, muſt be very far diſtant. Now by Experience we find the little force that Iron Guns have upon the Compaſs in Ships (their Vertue, tho' they be demiculverin, or greater Cannon, being not perceptible at four or five Yards diſtance) and the Experiments now before the *Royal Society* do plainly ſhew, how little a Magnetiſm there is in moſt crude Iron Ores: What quantity thereof muſt be then ſuppos'd to make ſo powerful a Diverſion at two or three Thouſand Miles diſtance? Yet I cannot deny that in ſome places near the Shoar, or in Shoal-Water, the Needle may be irregularly directed from the aforeſaid Cauſes, and that not a little, as *Gaſſendus* gives a notable inſtance of the Iſland *Elba* in the Mediterranean Sea: But theſe differences from the general Direction are always ſigns of the nearneſs of thoſe Magnetical Subſtances, for the Production whereof that Iſland *Elba* has been famous from all Antiquity. Beſides, againſt both *Des Cartes* and *Gilbert*, the change of the variation, which has been within theſe Hundred Years laſt paſt more than 15 gr. at *London*, is an entire Demonſtration; tho' *Des Cartes* does not ſtick to ſay, that the tranſportation of Iron from place to place, and the growth of new Iron within the Earth, where there was none before, may be the cauſe thereof. The ſame holds likewiſe againſt the *Hypotheſis* of *Magnetical Fibres*, which *Kircher* maintains.

Now to propoſe ſomething that may anſwer the ſeveral appearances, and introduce nothing ſtrange in Philoſophy, after a great many cloſe Thoughts, I can come to no other Concluſion than that, *The whole Globe of the Earth is one great Magnet, having four Magnetical Poles, or Points of Attraction, near each Pole of the Equator Two; and that, in thoſe parts of the World which lye near adjacent to any one of thoſe Magnetical Poles, the Needle is governed thereby, the neareſt Pole being always predominant over the more remote.* The parts of the Earth wherein theſe

Magnetical *Poles* lie, cannot as yet be exactly
determin'd for want of ſufficient *Data* to pro-
ceed Geometrically ; but, as near as Conjecture
can reach, I reckon that the *Pole*, which is at
preſent neareſt to us, lies in or near the Meri-
1. dian of the Lands end of *England*, and not a-
bove ſeven Degrees from the Pole Arctick, by
this *Pole* the variations in all *Europe* and *Tartary*,
and the *North Sea* are principally govern'd,
2. tho' with regard to the other Northern Pole,
whoſe ſituation is in a *Meridian* paſſing about
the middle of *California*, and about 15 gr. from
the North Pole of the World ; to this the
Needle has chiefly reſpect in all the North *A-
merica*, and in the two Oceans on either ſide
thereof, from the *Azores* Weſtward to *Japan*,
and farther. The two Southern Poles are ra-
ther farther diſtant from the South Pole of the
3. World : The one about ſixteen Degrees there-
from, is in a Meridian, ſome twenty Degrees
to the Weſtward of *Magellan Straights*, or ninty
five Degrees Weſt from *London* : This com-
mands the Needle in all the *South-America*, in
the *Pacifick Sea*, and the greateſt part of the
Ethiopick Ocean. The Fourth and laſt *Pole*
4. ſeems to have the greateſt Power and largeſt
Dominions of all, as it is the moſt remote from
the Pole of the World, being little leſs than
20 Degrees diſtant there-from in the Meridian,
which paſſes through *Hollandia Nova* and the
Iſland *Celebes* about one hundred and twenty De-
grees Eaſt from *London* ; this Pole is predomi-
nant in the South part of *Africa*, in *Arabia* and
the *Red Sea*, in *Perſia*, *India*, and its Iſlands,
and all over the *Indian Sea*, from the Cape of
Good-Hope Eaſtwards to the middle of the great
South Sea that divides *Aſia* from *America*. This

ſeems to be the preſent Diſpoſition of the Magnetical Vertue throughout the whole Globe of the Earth; it remains to ſhew how this Hypotheſis makes out all the variations that have been obſerv'd of late; and how it anſwers to our ſeveral Remarks drawn from the Table. And firſt it is plain, that (our *European* North *Pole* being in the Meridian of the Lands end of *England*) all places more Eaſterly than that will have it on the Weſt ſide of their Meridian, and conſequently the Needle, reſpecting it with its Northern Point, will have a Weſterly variation, which will ſtill be greater as you go to the Eaſtwards, till you come to ſome Meridian of *Ruſſia* where 'twill be greateſt, and from thence decreaſe again. Thus at *Breſt* the variation is but 1¾ Degrees, at *London* 4½ Degrees; but at *Dantzick* ſeven Degrees Weſt. To the Weſtward of the Meridian of the Lands end, the Needle ought to have an Eaſterly variation; were it not that (by approaching the *American* Northern Pole, which lies on the Weſt ſide of the Meridian, and ſeems to be of greater force than this other) the Needle is drawn thereby Weſtwards, ſo as to counterballance the direction given by the *European Pole*, and to make a ſmall Weſt variation in the Meridian of the Lands end itſelf. Yet I ſuppoſe that about the Meridian of the Iſle *Tercera*, our neareſt Pole may ſo far prevail as to give the Needle a little turn to the Eaſt, tho' but for a very ſmall ſpace: The Counterballance of thoſe two Poles permitting no conſiderable variation in all the Eaſtern Parts of the *Atlantick* Ocean; nor upon the Weſt Coaſts of *England* and *Ireland*, *France*, *Spain* and *Barbary*. But to the Weſtwards of the *Azores* the Power of the *American*

Pole overcoming that of the *European* the Needle has chiefly reſpect thereto, and turns ſtill more and more towards it as you approach it. Whence it comes to paſs, that on the Coaſt of *Virginia*, *New-England*, *New-found-Land*, and in *Hudſon*'s-*Straights* the variation is Weſtward; that it decreaſes as you go from thence towards *Europe*, and that it is leſs in *Virginia* and *New-England*, than in *New-found-Land*, and *Hudſon*'s-*Straights*. This Weſterly variation again decreaſes, as you paſs over the *North America*; and about the Meridian of the middle of *California* the Needle again points due North; and from thence Weſtward to *Yedzo* and *Japan*, I make no doubt but the variation is Eaſterly, and half the Sea over no leſs than fifteen Degrees, if there be any truth in this Hypotheſis of mine. Therefore I propoſe this as a trial, that the whole may be ſcann'd thereby; and I conceive it will not be hard to know of the *Spaniards* how it is, who ſo frequently ſail through that Ocean, in their return from the *Manilha* Iſles. This Eaſt variation extends over *Japan*, *Yedzo*, *Eaſt-Tartary*, and part of *China*, till it meet with the Weſterly, which is govern'd by the *European* North Pole, and which I ſaid was greateſt ſomewherein *Ruſſia*.

Towards the Southern Pole the effect is much the ſame, only that here the South Point of the Needle is attracted. Hence it will follow, that the variation on the Coaſt of *Brazile*, at the River of *Plate*, and ſo on to the Straits of *Magellan* ſhould be Eaſterly (as in our third Remark); if we ſuppoſe a Magnetical Pole ſituate about twenty Degrees more Weſterly than the Straights of *Magellan*. And this Eaſterly variation doth extend Eaſtward over the greateſt part of the *Ethiopick* Sea, till it be counterpoiſed by the Vertue of the other Southern *Pole*; as it is about mid-way between the Cape of *Good-Hope*, and the Iſles of *Triſtan d' Acuntia.* From thence Eaſtwards, the *Aſian* South Pole (as I muſt take the liberty to call it) becoming prevalent, and the South point of the Needle being attracted thereby, there ariſes a Weſt variation very great in quantity and extent, becauſe of the great diſtance of this Magnetical Pole of the World. Hence it is, that in all the *Indian* Sea as far as *Hollandia Nova*, and farther, there is conſtantly Weſt variation; at that under the Equator itſelf it ariſes to no leſs than eighteen Degrees, where 'tis moſt. About the Meridian of the Iſland *Celebes*, being likewiſe that of this Pole, this Weſterly variation ceaſes, and an Eaſterly begins; which reaches, according to my Hypotheſis, to the middle of the *South-Sea* between *Zelandia Nova* and *Chili*, leaving room for a ſmall *Weſt Variation* govern'd by the *American* South Pole, which I ſhew'd to be in the *Pacifick Sea*, in the ſixth and ſeventh Remark.

What I have now ſaid, does plainly ſhew the ſufficiency of this Hypotheſis for ſolving the variations that are at this time obſerv'd in the temperate and frigid *Zones*, where the direction of the Needle chiefly depends upon the Counterpoiſe of the forces of two Magnetical Poles of the ſame Nature; and I ſuppoſe I have ſhewn how it comes to paſs, that under the ſame Meridian the variation ſhould be in one place 29½ Weſt, and another 20½ Eaſt; as I have noted in my ninth Remark.

In the *Torrid Zone*, and particularly under the Equinoctial, reſpect muſt be had to all four

Poles, and their Poſitions well conſider'd, otherwiſe it will not be eaſie to determine what the variations ſhall be; the neareſt Pole being always the ſtrongeſt; yet not ſo, as not to be counterballanc'd ſometimes by the united forces of two more remote, a notable Inſtance whereof is in our eighth Remark, where I took notice, that in ſailing from St. *Helena* by the Iſle of *Aſcenſion*, to the Equator, on a *NW*. Courſe the variation is very little Eaſterly, and in that whole Tract unalterable; for which I give this Reaſon, that the South *American* Pole (which is conſiderably the neareſt in the aforeſaid places) requiring a great Eaſterly variation is counterpoiſed by the contrary Attraction of the *North-American* and the *Aſian-South* Pole; each whereof ſingly are in theſe parts, weaker than the *American-South-Pole*; and upon the *NW*. Courſe, the diſtance from this latter is very little varied; and as you recede from the *Aſian-South-Pole*, the ballance is ſtill preſerv'd by the acceſs towards the *North-American-Pole*. I mention not in this caſe the *European North-Pole*, its Meridian being little remov'd from thoſe of theſe places; and of it ſelf requiring the ſame variations we here find. After the ſame manner we might proceed to conclude the variations in other places under and near the Equator; but I purpoſely leave it for an exerciſe to the Thoughts of the ſerious Reader, who is deſir'd to help his Imagination, by having before him a Map or Globe of the Earth: And to mark thereon the Magnetical Poles in the *Longitudes* and *Latitudes* I aſſign them. (*Vide Plat.* 2.)

Thus, I hope, I have not loſt my Pains and Study in this difficult Subject; believing that I have put it paſt doubt, *That there are in the Earth four ſuch Magnetical Points or Poles which occaſion the great variety and ſeeming irregularity which is obſerv'd in the variations of the Compaſs.* But to calculate exactly what it is, in any place aſſign'd, is what I dare not yet pretend to, tho' I could wiſh it were my happineſs to be able to oblige the World with ſo uſeful a piece of Knowledge; there are difficulties that occur, that render the thing as yet not feaſible, for firſt there are a great many Obſervations requiſite, which ought to be made at the ſame time; not at Sea, but aſhore, with greater Care and Attention than the generality of Sailors apply. And beſides it remains undetermin'd in what proportion the attractive Power decreaſes, as you remove from the Pole of a Magnet, without which it were a vain attempt to go about to calculate. There is yet a further difficulty, which is the change of the variation, one of the diſcoveries of this laſt Century; which ſhews, that it will require ſome hundreds of Years to eſtabliſh a compleat Doctrine of the Magnetical Syſtem. From the foregoing Table it ſhould ſeem, that all the Magnetical Poles had a motion Weſtward: But if it be ſo, 'tis evident, that it is not a Rotation about the Axis of the Earth; for then the variations would continue the ſame, in the ſame parallel of *Latitude* (the *Longitude* only changed) as much as is the motion of the Magnetical Poles, but the contrary is found by Experience; for there is no where in the Latitude of 15½ North between *England* and *America*, a variation of eleven Degrees Eaſt at this time;

as it was once here at *London*; it ſeems therefore, that our *European* Pole is grown nearer the Pole *Arctick* than it was heretofore, or elſe that it has loſt part of its Vertue. But whether theſe Magnetical Poles move altogether with one motion, or with ſeveral; whether equally or unequally; whether Circular or Libratory: If Circular, about what Center; if Libratory, after what manner; are Secrets as yet utterly unkown to Mankind, and are reſerv'd for the Induſtry of future Ages.

An Account of the Cauſe of the Change of the Variation of the Magnetical Needle, with an Hypotheſis of the Structure of the Internal parts of the Earth; as it was propoſed to the Royal Society *in one of their late Meetings. By Mr.* Edmund Halley.

HAving in the precedent Diſcourſe delivered a Theory of the Variation of the Magnetical Compaſs, wherein I did collect as many Obſervations as at that time I could procure, and having carefully compar'd them together, I came at length to this general concluſion, *That the Globe of the Earth might be ſuppoſed to be one great Magnet, having four Magnetical Poles or Points of Attraction, near each Pole of the Equator two; and that in thoſe parts of the World which lie near adjacent to any one of thoſe Magnetical Poles, the Needle is chiefly govern'd thereby; the neareſt Pole being always predominant over the more remote.* And I there have endeavour'd to ſtate and limit the preſent Poſition of thoſe Poles in the Surface of our Globe, which the Reader pleaſing to conſult will ſave us the pains of repeating. But after all, tho' that Diſcourſe was favourably receiv'd both at home and abroad, as ſeeming to render a tolerable account of the obſerv'd variations, yet I found two difficulties not eaſie to ſurmount, the one was, that no Magnet I had ever ſeen or heard of, had more than two oppoſite Poles, whereas the Earth had viſibly four, and perhaps more. And ſecondly, it was plain that theſe Poles were not, at leaſt all of them, fixt in the Earth, but ſhifted from place to place, as appear'd by the great changes in the Needles direction within this laſt Century of Years, not only at *London*, (where this great Diſcovery was firſt made) but almoſt all over the Globe of Earth; whereas it is not known or obſerv'd that the Poles of a Load-ſtone ever ſhifted their place in the Stone, nor (conſidering the compact hardneſs of that ſubſtance) can it eaſily be ſuppos'd; tho' the matter of Fact be too notorious and univerſal, not to be accounted for.

Theſe difficulties had wholly made me deſpond, and I had long ſince given over an Inquiry I had ſo little hopes of, when in accidental Diſcourſe, and leaſt expecting it, I ſtumbl'd on the following Hypotheſis; in delivering whereof, if I ſhall ſeem to advance any thing that looks like Extravagant or Romantick, the Reader is deſir'd to ſuſpend his Cenſure, till he have conſider'd the force and number of the many Arguments which concur to make good ſo new and ſo bold a Suppoſition.

Tho' it be ſufficiently known and allow'd, that the Needles variation changes, it will be neceſſary however to give a few inſtances, whereby it may appear that this change is gradual and univerſal, and the effect of a great and permanent motion; For which take the following Examples.

At *London*, in the Year 1580, the variation was obſerv'd by Mr. *Burrows* to be 11° 15' Eaſt. In *Anno* 1622, the ſame was found by Mr. *Gunter* to be but 6° 0' Eaſt. In the Year 1634, Mr. *Gellibrand* found it 4°. 5' Eaſt. In 1657, Mr. *Bond* obſerv'd that there was no variation at *London*. *Anno* 1672, my ſelf obſerv'd it 2°. 30' to the Weſt; and in the Year 1692, I again found it 6° 00' Weſt. So that in 112 Years the direction of the Needle has chang'd no leſs than ſeventeen Degrees.

At *Paris*. *Orontius Finæus* about the Year 1550, did account it about eight or nine Degrees Eaſt variation. *Anno*. 1640, it was found three Degrees Eaſt. *Anno* 1666, there was no variation there, and *Anno* 1681, I found it to be 2° 30' to the Weſt.

At *Cap. d' Agulhas*, the moſt Southerly Promontary of *Africa*, about the Year 1600, the Needle pointed due North and South without variation, whence the *Portugueze* gave its name. *Anno* 1622, there was two Degrees Weſt variation. *Anno* 1675, it was 8°. 00 Weſt; and in the Year 1691, it was curiouſly obſerv'd not leſs than eleven Degrees Weſt.

At St. *Helena*, about the Year 1600, the Needle declin'd eight Degrees to the Eaſt. *Anno* 1623, it was but 6°. 00' Eaſt. *Anno* 1677, when I was there, I obſerv'd it accurately on Shoar to be 0*d.* 40' Eaſt; and in 1692 it was found about 1 *d.* to the Weſtward of the North.

At *Cape Comorine* in *India*, in the Year 1620, there was 14 gr. 20' Weſt variation. In the Year 1680, there was 8°. 48', but now lately in the Year 1688, it was no more than 7°. 30', ſo that here the Needle has return'd to the Eaſt about ſeven Degrees in ſeventy Years.

In all the other Examples the Needle has gradually mov'd towards the Weſt, and the places are too far aſunder to be influenc'd by the removal of any Magnetical Matter, which may by accident be tranſplac'd within the Bowels, or on the Surface of the Earth. If more Examples are deſir'd, the Reader may be furniſh'd with them in the *Portugueze Routier* of *Aleixo de Motta* (written about the Year 1600) and in the Voyage of *Beaulieu*, both publiſh'd in Mr. *Thevenot*'s firſt Collecton of curious Voyages, Printed at *Paris*, *Anno* 1663; which he is to compare with the Journals of our late *Eaſt India* Voyagers, and I am aſſur'd, that it will be thereby evident, that the direction of the Needle is in no place fix'd and conſtant, tho' in ſome it change faſter than in others: And where for a long time it has continu'd as it were unalter'd, it is there to be underſtood, that the Needle has its greateſt Deflection, and is become Stationary in order to return, like the Sun, in the Tropick. This, at preſent, is in the *Indian-Sea*, about the Iſland *Mauritius*, where is the higheſt Weſt variation, and in a Tract tending from thence into the N. N. W. towards the *Red-Sea* and *Egypt*. And in all Places to the Weſtward of this Tract, all over *Africa* and the Seas adjoining, the Weſt variation will be found to have encreas'd; and to the Eaſtwards thereof, as in the Example of *Cape Comorine*, to have decreas'd, *viz.* all over the *Eaſt-Indies* and the Iſlands near it.

After the like manner in that Space of Eaſt variation, which, beginning near St. *Helena*, is found all over the South *America*, and which at preſent is higheſt about the Mouth of *Rio de la Plata*, it has been obſerv'd, that in the Eaſtern

Parts thereof, the variation of the Needle gradually decreaſes; but whether on the contrary it increaſes in thoſe places which lie more Weſterly than that Tract wherein the higheſt Eaſt variation is found; or how it may be in the vaſt *Pacifick-Sea*, we have not Experience enough to aſcertain, only we may by Analogy infer, that both the Eaſt aud Weſt variations therein do gradually increaſe and decreaſe after the ſame Rule.

Theſe *Phænomena* being well underſtood and duly conſider'd, do ſufficiently evince, That the whole Magnetical Syſtem is by one, or perhaps more motions tranſlated, whether Eaſtwards or Weſtwards, I ſhall anon diſcuſs; that this moving thing is very great, as extending its effects from Pole to Pole; and that the motion thereof it not *per ſaltum*, but a gradual and regular motion.

Now conſidering the Structure of our *Terraqueous* Globe, it cannot be well ſuppos'd that a very great part thereof can move within it, without notably changing its Center of Gravity and the Equilibre of its Parts, which would produce very wonderful Effects in changing the Axis of diurnal Rotation, and occaſion ſtrange alteration in the Seas Surface, by Inundations and Receſſes thereof, ſuch as Hiſtory never yet mention'd. Beſides, the ſolid parts of the Earth are not to be granted permeable by any other than fluid Subſtances, of which we know none that are any ways Magnetical. So that the only way to render this motion intelligible and poſſible, is, to ſuppoſe it to turn about the Center of the Globe, having its Center of Gravity fix'd and immoveable in the ſame common Center of the Earth: And there is yet requir'd, that this moving internal Subſtance be looſe and detached from the external Parts of the Earth whereon we live; for otherwiſe were it affix'd thereto, the whole muſt neceſſarily move together.

So then the External Parts of the Globe may well be reckon'd as the Shell, and the Internal as a *Nucleus* or inner Globe included within ours, with a fluid medium between, which having the ſame common Center and Axis of diurnal Rotation, may turn about with our Earth each twenty four Hours; only this outer Sphere having its turbinating motion ſome ſmall matter either ſwifter or ſlower than the internal Ball: And a very Minute difference in length of time, by many repetitions becoming ſenſible, the Internal Parts will by degrees recede from the External, and not keeping pace with one another will appear gradually to move either Eaſtwards or Weſtwards by the difference of their motions.

Now ſuppoſing ſuch an Internal Sphere having ſuch a motion, we ſhall ſolve the two great Difficulties we encounter'd in my former Hypotheſis: For if this exterior Shell of Earth be a Magnet having its Poles at a diſtance from the Poles of diurnal Rotation; and if the Internal *Nucleus* be likewiſe a Magnet, having its Poles in two other places diſtant alſo from the Axis; and theſe latter by a gradual and ſlow motion change their place in reſpect of the External; we may then give a reaſonable account of the four Magnetical Poles I preſume to have demonſtrated before; as likewiſe of the changes of the Needles variations, which till now hath been unattempted.

The Period of this motion being wonderful great, and there being hardly an hundred Years ſince theſe Variations have been duly obſerv'd, it will be very hard to bring this Hypotheſis to a Calculus, eſpecially ſince, tho' the Variations do increaſe and decreaſe regularly in the ſame place, yet in differing places, at no great diſtance, there are found ſuch caſual Changes thereof as can no ways be accounted for by a regular Hypotheſis; as depending upon the unequal and irregular diſtribution of the Magnetical Matter within the ſubſtance of the external Shell or Coat of the Earth, which deflect the Needle from the Poſition it would acquire from the effect of the general Magnetiſm of the whole. Of this the Variations at *London* and *Paris* give a notable inſtance, for the Needle has been conſtantly about 1° ½ more Eaſterly at *Paris* than at *London*; tho' it be certain that according to the general effect, the difference ought to be the contrary way: Notwithſtanding which the Variations in both places do change alike.

Hence, and from ſome other of like Nature, I conclude, That the two Poles of the external Globe are fixt in the Earth, and that if the Needle were wholly govern'd by them, the Variations thereof would be always the ſame, with ſome little Irregularities upon the account I but juſt now mention'd: But the internal Sphere having ſuch a gradual tranſlation of its Poles, does influence the Needle, and direct it variouſly according to the reſult of the attractive or directive Power of each Pole; and conſequently there muſt be a Period of the Revolution of this internal Ball, after which the Variations will return again as before. But if it ſhall in future Ages be obſerv'd otherwiſe, we muſt then conclude that there are more of theſe Internal Spheres, and more Magnetical Poles than Four, which at preſent we have not a ſufficient number of Obſervations to determine, and particularly in that vaſt *Mar del Zur*, which occupies ſo great a part of the whole Surface of the Earth.

If then two of the Poles be fixt and two moveable, it remains to aſcertain which they are that keep their place; and tho' I could wiſh we had the experience of another Century of Years to found our Concluſions upon, yet I think we may ſafely determine, *That our European NorthPole* (which in the precedent Diſcourſe I ſuppos'd near theMeirdian of the Lands end of *England*, and about 7 Degrees therefrom) is that That is moveable of the two Northern Poles, and that That has chieflly influenc'd the Variations in theſe parts of the World: For in *Hudſon*'s Bay, which is under the Direction of the *American* Pole, the change is not obſerv'd to be near ſo faſt as in theſe parts of *Europe*, tho' that Pole be much farther remov'd from the Axis.

As to the *South Poles*, I take the *Aſian* Pole, which I place about the Meridian of the Iſland *Celebes* to be the fixt, and conſequently the *American* Pole to move; from the like Obſervation of the ſlow Decreaſe of the Variation on the Coaſt of *Java*, and near the Meridian of the *Aſian* Pole; tho' I muſt confeſs to have no account of the effects of the other beyond *Magellan*'s Streights.

If this be allow'd me, 'tis plain that the fixt Poles are the Poles of this External Shell or Cortex of the *Earth*, and the other two the Poles of a Magnetical *Nucleus* included and moveable within the other. It likewiſe follows, that this Motion is Weſtwards, and by conſequence that the aforeſaid *Nucleus* has not preciſely attained the ſame degree of Velocity with the exteriour Parts in their diurnal Revolution; but ſo very nearly equals it, that in 365 Revolves the difference is ſcarce ſenſible. This I conceive to ariſe from the Impulſe whereby this diurnal Motion was impreſt on the Earth, being given to the external Parts, and from thence in time communicated to the Internal; but not ſo as perfectly to equal the Velocity of the firſt Motion impreſs'd on, and ſtill conſerv'd by the ſuperficial Parts of the Globe.

As to the Quantity of this Motion it is almoſt impoſſible to define it, both from the Nature of this kind of Obſervation, which cannot be very accurately perform'd, as alſo from the ſmall time theſe Variations have been obſerv'd, and their change diſcover'd. It appears by all Circumſtances, that its Period is of many Centuries of Years, and as far as may be collected from the Change of the Place, where there was no Variation by reaſon of the Equilibre of the two Southern Magnetical Poles, *viz.* from *Cape d' Agulhas* to the Meridian of St. *Helena* (which is about 23^{gr} in about ninty Years) and of the place where the Weſterly Variation is in its ἀκμὴ or greateſt Deflection, being about half ſo much, *viz.* from the Iſle of *Diego Roiz* to the South Weſt Parts of *Madagaſcar*. We may with ſome Reaſon conjecture, that the *American* Pole has mov'd Weſtwards fourty ſix Degrees in that time, and that the whole Period thereof is perform'd in ſeven hundred Years, or thereabouts; ſo that the nice Determination of this and of ſeveral other particulars in the

Magnetick Syſtem is reſerv'd for remote Poſterity; all that we can hope to do, is to leave behind us Obſervations that may be confided in, and to propoſe Hypotheſis which after Ages may examine, amend or refute. Only here I muſt take leave to recommend to all Maſters of Ships and all others, Lovers of Natural Truths, that they uſe their utmoſt Diligence to make, or procure to be made, Obſervations of theſe Variations in all parts of the World, as well in the North as South Latitude (after the laudable Cuſtom of our *Eaſt-India* Commanders) and that they pleaſe to communicate them to the *Royal Society*, in order to leave as compleat a Hiſtory as may be to thoſe that are hereafter to compare all together, and to compleat and perfect this abſtruſe Theory.

And by the way it will not be amiſs to amend a receiv'd Error in the Practice of obſerving the Variation, which is, to take it by the Amplitude of the Riſing and Setting Sun, when his Center appears in the viſible Horizon; whereas he ought to be obſerv'd when his under Limb is ſtill above the Horizon about ⅔ of his Diameter, or twenty Minutes, upon the ſcore of the Refraction, and the height of the Eye of the Obſerver above the Surface of the Sea: Or elſe they are to work the Amplitudes as they do the Azimuth, reckoning the Suns diſtance from the Zenith 90°. 36′: This, tho' it be of little conſequence near the Æquinoctial, will make a great error in high Latitudes, where the Sun riſes and ſets obliquely.

But to return to our Hypotheſis, In order to explain the change of the Variations, we have adventur'd to make the Earth hollow and to place another Globe within it; and I doubt not but this will find Oppoſers enough. I know 'twill be Objected, That there is no Inſtance in Nature of the like thing; that if there was ſuch a middle Globe it would not keep its place in the Centre, but be apt to deviate there-from, and might poſſibly chock againſt the Concave Shell, to the ruine, or at leaſt endammaging thereof; That the Water of the Sea would perpetually leak through, unleſs we ſuppoſe the Cavity full of Water; That were it poſſible, yet it does not appear of what uſe ſuch an inward Sphere can be of, being ſhut up in eternal Darkneſs, and therefore unfit for the Production of Animals or Plants; with many more Objections, according to the Fate of all ſuch new Propoſitions.

To theſe, and all other that I can foreſee, I briefly Anſwer, That the Ring environing the Globe of *Saturn* is a notable Inſtance of this kind, as having the ſame common Center, and moving along with the Planet, without ſenſibly approachihg him on one ſide more than the other. And if this Ring were turn'd on one of its Diameters, it would then deſcribe ſuch a Concave Sphere as I ſuppoſe our External one to be. And ſince the Ring, in any Poſition given, would, in the ſame manner, keep the Centre of *Saturn* in its own, it follows, that ſuch a Concave Sphere may move with another included in it, having the ſame common Centre. Nor can it well be ſuppos'd otherwiſe, conſidering the Nature of Gravity; for ſhould theſe Globes be adjuſted once to the ſame common Centre, the Gravity of the parts of the Concave would preſs equally towards the Centre of the inner Ball, which equality muſt neceſſarily continue till ſome external Force diſturb it, which is not eaſie to imagine in our caſe. This perhaps I might more intelligibly expreſs, by ſaying that the inner Globe being poſited in the Centre of the Exterior, muſt neceſſarily aſcend which way ſoever it move; that is, it muſt overcome the force of Gravity preſſing towards the common Centre, by an impulſe it muſt receive from ſome outward Agent; but all outward Efforts being ſufficiently fenc'd againſt by the Shell that ſurrounds it, it follows, that this *Nucleus* being once fixt in the common Centre, muſt alwas there remain.

As to the leaking of the Water through this Shell, when once a paſſage ſhall be found for it to run through, I muſt confeſs it is an Objection ſeemingly of weight; but when we conſider how tightly great Beds of Chalk or Clay, and much more Stone do hold Water, and even Caves arch'd with Sand; no Man can doubt but the Wiſdom of the Creator has provided for the Macrocoſm by many more ways than I can either imagine or expreſs, eſpecially ſince we ſee the admirable and innumerable Contrivances wherewith each worthleſs Individual is furniſh'd both to defend itſelf and propagate its Species. What Curioſity in the Structure, what Accuracy in the Mixture and Compoſition of the parts ought not we to expect in the Fabrick of this Globe, made to be the laſting Habitation of ſo many various Species of Animals, in each of which there want not many Inſtances that manifeſt the boundleſs Power and Goodneſs of their Divine Author; and can we then think it a hard ſuppoſition that the Internal Parts of this Bubble of Earth ſhould be replete with ſuch Saline and Vitriolick Particles as may contribute to Petrifaction, and diſpoſe the tranſuding Water to ſhoot and coagulate into Stone, ſo as continually to fortifie, and, if need were, to conſolidate any breach or flaw in the Concave ſurface of the Shell.

And this perhaps may not without reaſon be ſuppos'd to be the final Cauſe of the admixture of the Magnetical Matter in the Maſs of the Terreſtial parts of our Globe, *viz.* To make good and maintain the Concave Arch of this Shell: For by what the excellent Mr. *Newton* has ſhewn in his *Principia Philoſophiæ*, it will follow, that according to the general Principle of Gravity, viſible throughout the whole Univerſe, all thoſe Particles that by length of time or otherwiſe, ſhall moulder away or become looſe on the Concave Surface of the External Sphere, would fall in, and with great force deſcend on the Internal, unleſs thoſe Particles were of another ſort of Matter capable by their ſtronger tendency to each other, to ſuſpend the force of Gravity; but we know no other Subſtances capable of ſupporting each other by their mutual Attraction but the Magnetical, and theſe we ſee miraculouſly to perform that Office, even where the Power of Gravity has its full effect, much more within the Globe where it is weaker. Why then may we not ſuppoſe theſe ſaid Arches to be lin'd throughout with a Magnetical Matter, or rather to be one great Concave Magnet, whoſe two Poles are the Poles we have before obſerv'd to be fixt in the Surface of our Globe.

Another Argument, favouring this Hypotheſis, is drawn from a Propoſition of the ſame Mr. *Newton*, where he determines the force wherewith the *Moon* moves the *Sea* in producing the *Tides:* His words are, *Denſitas Lunæ eſt ad denſitatem Terræ ut* 680 *ad* 387 *ſeu* 9 *ad* 5 *quamproxime. Eſt igitur corpus Lunæ denſius ac magis tereſtre quam Terra noſtra*, p. 466. Now if the Moon be more ſolid than the Earth, as 9 to 5, why may we not reaſonably ſuppoſe the Moon, being a ſmall Body and a Secondary Planet, to be ſolid Earth, Water, Stone, and this Globe to conſiſt of the ſame Materials, only four Ninths thereof to be Cavity, within and between the internal Spheres; which I would render not improbable.

To thoſe that ſhall enquire of what uſe theſe included Globes can be, it muſt be allow'd, that they can be of very little ſervice to the Inhabitants of this outward World, nor can the Sun be ſerviceable to them, either with his Light or Heat. But ſince it is now taken for granted, that the Earth is one of the Planets, and they all are with reaſon ſuppos'd Habitable, though we are not able to define by what ſort of Animals; and ſince we ſee all the parts of the Creation abound with Animate Beings, as the Air with Birds and Flies, the Water with the numerous varieties of Fiſh, and the very Earth with Reptiles of ſo many ſorts; all whoſe ways of Living would be to us incredible did not daily Experience teach us. Why then ſhould we think it ſtrange that the prodigious Maſs of Matter, whereof this Globe does conſiſt, ſhould be capable of ſome other improvement than barely to ſerve to ſupport its Surface? Why may not we rather ſuppoſe that the exceeding ſmall quantity of ſolid Matter in reſpect of the fluid Æther, is ſo diſpos'd by the Almighty Wiſdom, as to yield as great a Surface for the uſe of living Creatures, as can conſiſt with the conveniency and ſecurity of the whole? We our ſelves, in Cities where we are preſſed for room, commonly build many Stories one over the other, and thereby accommodate a much greater multitude of Inhabitants.

But ſtill it will be ſaid, that without Light there can bo no living, and therefore all this *apparatus* of our inward Globes muſt be uſeleſs: To this I Anſwer, That there are many ways of producing Light which we are wholly ignorant of; the Medium itſelf may be always luminous after the manner of our *Ignes fatui.* The Concave Arches may in ſeveral places ſhine with ſuch a Subſtance as inveſts the Surface of the Sun; nor can we, without a boldneſs unbecoming a Philoſopher, adventure to aſſert the impoſſibility of peculiar Luminaries below, of which we have no ſort of *Idea.* I am ſure the Poets *Virgil* and *Claudian* have gone before me in this Thought, inlightning their *Elyſian Fields* with Sun and Stars proper to thoſe infernal, or rather internal, Regions. *Virg. Æneid. 6.*

Largior hic compos Æther & lumine veſtit.
Purpureo; Solemque ſuum ſua Sideranorunt.

And *Claudian* lib. 2. *De Raptu Proſerpinæ.*

Amiſſum ne crede diem, ſunt altera nobis
Sidera, ſunt orbes alii, lumenque videbis
Purius, Elyſiumque magis mirabere Solem.

And tho' this be not to be eſteem'd as an Argument, yet I may take the liberty I ſee others do, to quote the Poets when it makes for my purpoſe.

Laſtly,

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Laſtly, To explain yet farther what I mean, I have adventur'd to adjoin the following Scheme, (*Table* 1. *Fig.* 3.) wherein the Earth is repreſented by the outward Circle, and the three inward Circles are made nearly proportionable to the Magnitudes of the Planets *Venus*, *Mars* and *Mercury*, all which may be included within the Globe of Earth, and all the Arches more than ſufficiently ſtrong to bear their weight. The Concave of each Arch, which is ſhaded differently from the reſt, I ſuppoſe to be made up of Magnetical Matter; and the whole to turn about the ſame common Axis *p*, *p*, only with this difference, that the Outer Sphere ſtill moves ſomewhat faſter than the Inner. Thus the Diameter of the Earth being about eight thouſand *Engliſh* Miles, I allow five hundred Miles for the thickneſs of its Shell, and another ſpace of five hundred Miles for a Medium between, capable of an immenſe Atmoſphere for the uſe of the Globe of *Venus*: *Venus* again I give a Shell of the ſame thickneſs, and leave as great a ſpace between her Concave and *Mars*; ſo likewiſe from *Mars* to *Mercury*, which latter Ball we will ſuppoſe ſolid, and about two thouſand Miles Diameter. Thus I have ſhew'd a poſſibility of a much more ample Creation, than has hitherto been imagin'd; and if this ſeem ſtrange to thoſe that are unaquainted with the Magnetical Syſtem, it is hop'd that all ſuch will endeavour, firſt, to inform themſelves of the Matter of Fact, and then try if they can find out a more ſimple Hypotheſis, at leaſt a leſs abſurd, even in their own Opinions. And whereas I have adventur'd to make theſe Subterraneous Orbs capable of being Inhabited, 'twas done deſignedly for the ſake of thoſe who will be apt to ask *cui bono*, and with whom Arguments drawn from *Final Cauſes* prevail much. If this ſhort Eſſay ſhall find a kind acceptance, I ſhall be encourag'd to enquire farther, and to Poliſh this rough Draft of a Notion till hitherto not ſo much as ſtarted in the World, and of which we could have no Intimation from any other of the *Phænomena* of Nature.

Since this was written, a Diſcovery I have made in the Celeſtial Motions, ſeems to render a farther account of the Uſe of the Cavity of the Earth, *viz*, To diminiſh the Specifick Gravity thereof in reſpect of the Moon; for I think I can demonſtrate that the Oppoſition of the Æther to the Motions of the Planets in long time becomes ſenſible; and conſequently the greater Body muſt receive a leſs Oppoſition than the ſmaller, unleſs the Specifick Gravity of the ſmaller do proportionably exceed that of the greater, in which caſe only they can move together; ſo that the Cavity I aſſign in the Earth, may well ſerve to adjuſt its weight to that of the Moon; for otherwiſe the Earth would leave the Moon behind it, and ſhe become another Primary Planet.

An Hiſtorical Account of the Trade Winds *and* Monſoons, *obſervable in the Seas between and near the* Tropicks, *with an attempt to aſſign the Phyſical Cauſe of the ſaid Winds, by Mr.* Ed. Halley.

AN exact Relation of the conſtant and Periodical Winds, obſervable in ſeveral Tracts of the Ocean, is a part of Natural Hiſtory not leſs deſireable and uſeful, than it is difficult to obtain, and its *Phænomena* hard to explicate: I am not ignorant that ſeveral Writers have undertaken this Subject, and altho' *Varenius (Lib.* 1. *Chap.* 21. *Geo. Gen.)* ſeems to have endeavour'd after the beſt information from *Voyagers*, yet cannot his accounts be admitted for accurate, by thoſe that ſhall attentively conſider and compare them together, and ſome of them are moſt evident miſtakes; which, as near as I can, I ſhall attempt to rectify, having had the opportunity of converſing with Navigators acquainted with all parts of *India*, and having liv'd a conſideable time between the *Tropicks*, and there made my own Remarks.

The Subſtance of what I have collected is briefly as follows.

The Univerſal *Ocean* may moſt properly be divided into three Parts, *viz.* 1. The *Atlantick* and *Æthiopick-Sea.* 2. The The *Indian Ocean.* 3.

3. The Great *South Sea*, or the *Pacifick Ocean*; and tho' theſe Seas do all communicate by the South, yet as to our preſent purpoſe of the *Trade Winds*, they are ſufficiently ſeperated by the interpoſition of great Tracts of *Land*; the firſt lying between *Africa* and *America*, the ſecond between *Africa*, and the *Indian Iſlands* and *Hollandia Nova*; and the laſt between the *Philippine Iſles*, *China*, *Japan* and *Hollandia Nova* on the *Weſt*, and the Coaſt of *America* on the *Eaſt*. Now following this natural diviſion of the Seas, ſo will we divide our Hiſtory into three parts in the ſame order.

I. In the *Atlantick* and *Æthiopick* Seas between the *Tropicks*, there is a general *Eaſterly Wind*, all the Year long, without any conſiderable Variation, excepting that it is ſubject to be deflected there-from, ſome few Points of the Compaſs towards the *North* or *South*, according to the Poſition of the place. The Obſervations which have been made of theſe Deflections, are the following.

1. That near the Coaſt of *Africa*, as ſoon as you have paſs'd the *Canary Iſles* you are ſure to meet a freſh Gale of *N. E.* Wind about the Latitude of 28 Degrees *North*, which ſeldom comes to the *Eaſtwards* of the *E. N. E.* or paſſes the *N. N. E.* This Wind accompanies thoſe bound to the Southward, to the Latitude of ten North, and about a hundred Leagues from the *Guinea* Coaſt, where, till the fourth Degree of North Latitude, they fall into the Calmes and Tornadoes, of which more hereafter.

2. That thoſe bound to the *Caribbe Iſles*, find, as they approach the *American* ſide, that the afore-ſaid North-Eaſt Wind, becomes ſtill more and more Eaſterly, ſo as ſometimes to be Eaſt, ſometimes Eaſt by South, but yet moſt commonly to the Northward of the Eaſt a Point or two, ſeldom more. 'Tis likewiſe obſerv'd, that the ſtrength of theſe Winds does gradually decreaſe, as you ſail to the Weſtwards.

3. That the limits of the Trade and variable Winds, in this Ocean, are farther extended on the *American* ſide than the *African*; for whereas you meet not with this certain Wind till after you have paſs'd the Latitude of twenty eight degrees on this ſide; on the *American* ſide it commonly holds to thirty, thirty one, or thirty two degrees of Latitude; and this is verified likewiſe to the Southwards of the Æqoinoctial, for near the *Cape* of *Good-Hope* the limits of the Trade Winds, are three or four Degrees nearer the Line, than on the Coaſt of *Brazile*.

4. That from the Latitude of four Degrees North, to the afore-ſaid Limits on the South of the Æquator, the Winds are generally and perpetually between the South and Eaſt, and moſt commonly between the South-Eaſt and Eaſt, obſerving always this Rule, that on the *African* ſide they are more Southerly, on the *Braſilian* more Eaſterly, ſo as to become almoſt due Eaſt, the little deflection they have being ſtill to the Southwards. In this part of the Ocean it has been my fortune to paſs a full Year, in an Employment that oblig'd me to regard more than ordinary the Weather, and I found the Winds conſtantly about the South-Eaſt, the moſt uſual Point *S E b E*; when it

was Eaſterly it generally blew hard, and was gloomy, dark, and ſometimes rainy Weather; if it came to the Southwards it was generally Serene, and a ſmall Gale next to a Calm, but this not very common. But I never ſaw it to the Weſtwards of the South, or Northwards of the Eaſt.

5. That the Seaſon of the Year has ſome ſmall effect on theſe Trade Winds, for that when the Sun is conſiderable to the Northwards of the Æquator, the South-Eaſt Winds, eſpecially in the Straight of this Ocean (if I may ſo call it) between *Braſile* and the Coaſt of *Guinea*, do vary a Point or two to the Southwards, and the North-Eaſt become more Eaſterly; and on the contrary, when the Sun is towards the Tropick of *Capricorn* the South-Eaſterly Winds become more Eaſterly, and the North-Eaſterly Winds on this ſide the Line vere more to the Northwards.

6. That as there is no general Rule that admits not of ſome exception, ſo there is in this Ocean a Tract of Sea wherein the Southerly and South-Weſt Winds are perpetual, *viz.* all along the Coaſt of *Guinea*, for above five hundred Leagues together, from *Sierra Leona* to the Iſle of St. *Thomas*; for the South-Eaſt Trade Wind having paſs'd the Line, and approaching the Coaſt of *Guinea* within eighty or 100 Leagues inclines towards the Shore and becomes S. S. E., and by Degrees, as you come nearer, it veres about to South, S. S. Weſt, and in with the Land South-Weſt, and ſometimes Weſt South-Weſt; which Variation is better expreſs'd in the Mapp hereto annexed, (*Vide Plate* 2.) than it can well be in words. Theſe are the Winds which are obſerv'd on this Coaſt when it

blows true, but there are frequent Calms, Violent ſuddain Guſts call'd *Tornado's*, from all Points of the Compaſs, and ſometimes unwholſome foggy Eaſterly Winds call'd *Hermitaa* by the Natives, which too often infeſt the Navigation of theſe parts.

7. That to the Northwards of the Line, between four and ten Degrees of Latitude, and between the Meridians of *Cape Virde*, and of the Eaſtermoſt Iſlands that bear that Name, there is a Tract of Sea wherein it were improper to ſay there is any Trade Wind, or yet a Variable; for it ſeems condemn'd to perpetual Calms, attended with terrible Thunder and Lightning, and Rains ſo frequent, that our Navigators from thence call this part of the Sea the *Rains*; the little Winds that are, be only ſome ſuddain uncertain Guſts, of very little continuance and leſs extent; ſo that ſometimes each hour you ſhall have a different Gale, which dies away into a Calm before another ſucceed, and in a Fleet of Ships in ſight of one another, each ſhall have the Wind from a ſeveral Point of the Compaſs; with theſe weak *Brizes* Ships are oblig'd to make the beſt of their way to the Southward through the afore-ſaid ſix Degrees, wherein 'tis reported ſome have been detain'd whole Months for want of Wind.

From the three laſt obſervables is ſhewn the Reaſon of two notable Occurents in the *Eaſt-India* and *Guinea* Navigations: The one is, why, notwithſtanding the narroweſt part of the Sea between *Guinea* and *Braſile* be about five hundred Leagues over, yet Ships bound to the Southward ſometimes, eſpecially in the Months of *July* and *Auguſt*, find a great difficulty to paſs it. This happens becauſe of the South-

Eaſt Winds, at that time of the Year commonly extending ſome Degrees beyond the ordinary limit of four Degrees North Latitude, and withal they come ſo much Southerly, as to be ſometimes South, ſometimes a Point or two to the Weſt; there remains then only to ply to Wind-ward, and if on the one ſide they ſtand away W. S. W. they gain the Wind ſtill more and more Eaſterly, but there is danger of not weathering the *Braſilian* Shore, or at leaſt the Shoals upon that Coaſt. But if upon the other Tack they go away E. S. E. they fall into the Neighbourhood of the Coaſt of *Guinea*, from which there is no departing without running Eaſterly, as far as the Iſle of St. *Thomas*, which is the conſtant practiſe of all the *Guiny* Ships, and which may ſeem very ſtrange without the conſideration of the ſixth Remark, which ſhews the reaſon of it: For being in with the Coaſt, the Wind blows generally at S. W. and W. S. W. with which Winds they cannot go to the Northward for the Land, and on the other Tack they can lie no nearer the Wind than S. S. E. or South; with theſe Courſes they run off the Shore, but in ſo doing they always find the Winds more and more contrary; ſo that when near the Shore they could lie South, at a greater diſtance they can make their way no better than S. E. and afterwards E.S.E. with which courſes they fetch commonly the Iſle of St. *Thomas* and Cape *Lopez*, where finding the Winds to the Eaſtward of the South, they keep them favourable by running away to the Weſtward in the South Latitude, of three or four Degrees, where the S. E. Winds are perpetual.

For the ſake of theſe general Winds, all thoſe that uſe the *Weſt-Indian* Trade, even thoſe bound to *Virginia*, count it their beſt courſe to get as ſoon as they can to the Southwards, that ſo they may be certain of a fair and freſh Gale to run before it to the Weſtwards; and for the ſame reaſon thoſe homewards bound from *America*, endeavour to gain the Latitude of thirty Degrees, as ſoon as poſſible, where they firſt find the Winds begin to be Variable; though the moſt ordinary Winds in the Northern part of the *Atlantick* Ocean come from between the South and Weſt.

As to thoſe furious Storms call'd *Hurricanes*, which are, as it were, peculiar to the *Caribbe* Iſles; and which ſo dreadfully afflict them in the Month of *Auguſt*, or not much before or after, they do not ſo properly belong to this place, both by reaſon of their ſmall continuance and extent, as likewiſe becauſe they are not Anniverſary, ſome Years having more than one, and ſometimes for ſeveral Years together there being none at all. But their Violence is ſo unconceivable, and their other *Phænomena* ſo ſurpriſing, that they merit well to be conſider'd apart.

What is here ſaid, is to be underſtood of the Sea Winds at ſome diſtance from the Land; for upon and near the Shores, the Land and Sea Brizes are almoſt every where ſenſible; and the great Variety which happens in their Periods, Force and Direction, from the ſituation of the Mountains, Vallies and Woods, and from the various Texture of the Soil, more or leſs capable of retaining and reflecting Heat, and of exhaling or condenſing Vapours is ſuch, that it were an endleſs task, to endeavour to account for them.

II. In the *Indian* Ocean, the Winds are partly general, as in the *Æthiopick* Ocean, partly Periodical, that is, half the Year they blow one way, and the other half near upon the oppoſite Points; and theſe Points and Times of ſhifting are diffeent in different parts of this Ocean; the limits of each tract of Sea, ſubject to the ſame change or *Monſoon*, are certainly very hard to determine, but the diligence I have uſed to be rightly inform'd, and the care I have taken therein, has, in a great meaſure, ſurmounted that difficulty, and I am perſwaded that the following particulars may be relied upon.

1. That between the Latitudes of ten Degrees and thirty Degrees South, between *Madagaſcar* and *Hollandia Nova*, the general Trade Wind about the S. E. by E. is found to blow all the Year long, to all Intents and Purpoſes after the ſame manner as in the ſame Latitudes in the *Æthiopick* Ocean, as it is deſcribed in the fourth *Remark* aforegoing.

2. That the aforeſaid S. E. Winds extend to within two Degrees of the *Æquator*, during the Months of *June*, *July*, *Auguſt*, &c. to *November*, at which time between the *South Latitudes* of three and ten Degrees, being near the Meridian of the North end of *Madagaſcar*, and between two and twelve South Latitude, being near *Sumatra* and *Java*, the contrary Winds from the N. W. or between the *North* and Weſt, ſet in and blow for half the Year, *viz.* from the beginning of *December* till *May*; and this *Monſoon* is obſerv'd as far as the *Molucca* Iſles, of which more anon.

3. That to the Northward of three Degrees South Latitude, over the whole *Arabian* or *Indian-Sea* and Gulph of *Bengall*, from *Sumatra* to the Coaſt of *Africa*, there is another *Monſoon*, blowing from *October* to *April* upon the North Eaſt Points; but in the other half Year, from *April* to *October*, upon the oppoſite Points of S. W. and W. S. W. and that with rather more force than the other accompanied with dark rainy Weather, whereas the N. E. blows clear; 'tis likewiſe to be noted, that the Winds are not ſo conſtant, either in ſtrength or point in the Gulph of *Bengall*, as they are in the *Indian-Sea*, where a certain and ſteady Gale ſcarce ever fails. 'Tis alſo remarkable, that the S. W. Winds in theſe Seas are generally more Southerly on the *African* ſide, more Weſterly on the *Indian*.

4. That as an *Appendix* to the laſt deſcribed *Monſoon*, there is a Tract of Sea to the Southwards of the Æquator, ſubject to the ſame changes of the Winds, *viz.* near the *African*-Coaſt, between it and the Iſland *Madagaſcar* or St. *Laurence*, and from thence Northwards as far as the Line; wherein from *April* to *October* there is found a conſtant freſh S. S. W. Wind, which, as you go more Northerly, becomes ſtill more and more Weſterly, ſo as to fall in with the W. S. W. Winds, mention'd before, in thoſe Months of the Year to be certain to the Northward of the Æquator: What Winds blow in theſe Seas, for the other half Year, from *October* to *April*, I have not yet been able to obtain to my full ſatisfaction, for that our Navigators always return from *India* without *Madagaſcar*, aud ſo are little acquainted in this matter; the Account that has been given me is

only this, that the Winds are much Eaſterly hereabouts, and as often to the North of the true Eaſt as to the Southwards thereof.

5. That to the Eaſtward of *Sumatra* and *Malacca*, to the Northwards of the Line, and along the Coaſt of *Camboia* and *China*, the *Monſoons* blow North and South, that is to ſay, the N. E. Winds are much Northerly, and the S. W. much Southerly: This Conſtitution reaches to the Eaſtwards of the *Philippine*-Iſles, and as far Northerly as *Japan*. The Northern *Monſoon* ſetting in, in theſe Seas, in *October* or *November*, and the Southern in *May*, blowing all the Summer Months: Here it is to be noted, That the Points of the Compaſs, from whence the Wind comes in theſe Parts of the World, are not ſo fixt as in thoſe lately deſcrib'd; for the Southerly will frequently paſs a Point or two to the Eaſtwards of the South, and the Northerly as much to the Weſtwards of the North, which ſeems occaſion'd by the great quantity of Land which is interſpers'd in theſe Seas.

6. That in the ſame *Meridians*, but to the Southwards of the Æquator, being that Tract lying between *Sumatra* and *Java* to the Weſt, and New *Guinea* to the Eaſt, the ſame Northerly *Monſoons* are obſerv'd, but with this difference, that the inclination of the Northerly is towards the N. W. and of the Southerly towards the S. E. but the *plagæ venti* are not more conſtant here than in the former, *viz.* variable five or ſix Points; beſides the times of the Change of theſe Winds, are not the ſame as in the *Chineſe* Seas, but about a Month or ſix Weeks later.

7. That theſe contrary Winds do not ſhift all at once, but in ſome places the time of the change is attended with Calms, in others with variable Winds; and it is particularly remarkable, that the end of the Weſterly *Monſoon* on the Coaſt of *Coromandel*, and the two laſt Months of the Southerly *Monſoon* in the Seas of *China* are very ſubject to be tempeſtuous: The violence of theſe Storms is ſuch, that they ſeem to be of the Nature of the *Weſt-India Hurricanes*, and render the Navigation of theſe parts very unſafe about that time of the Year. Theſe Tempeſts are by our Seamen uſually term'd, *The breaking up of the Monſoons.*

By reaſon of the ſhifting of theſe Winds, all thoſe that ſail in theſe Seas, are oblig'd to obſerve the Seaſons proper for their Voyages, and ſo doing they fail not of a fair Wind and ſpeedy Paſſage; but if ſo be they chance to out-ſtay their time till the contrary *Monſoon* ſet in, as it frequently happens, they are forc'd to give over the hopes of accompliſhing their intended Voyages, and either return to the Port from whence they came, or elſe put in to ſome other Harbour, there to ſpend the time till the Winds ſhall come favourable.

III. The third Ocean call'd *Mare Pacificum*, whoſe extent is equal to that of the other two (it being from the Weſt Coaſt of *America* to the *Philippine* Iſlands, not leſs than 150 Degrees of Longitude) is that which is leaſt known to our own or the Neighbour Nations; that Navigation that there is on it, is by the *Spaniards*, who go Yearly from the Coaſt of New *Spain* to the *Manilha*'s, but that but by one beaten track; ſo that I cannot be ſo particular here as in the other two. What the *Spaniſh* Authors ſay of the Winds they find in their Courſes, and what is confirm'd by the old Accounts of *Drake* and *Candiſh*, and ſince by *Schooten*, who ſail'd the whole breadth of this Sea in the Southern Latitude of fifteen or ſixteen Degrees, is, that there is a great conformity between the Winds of this Sea, and thoſe of the *Atlantick* and *Æthiopick*; that is to ſay, that to the Northwards of the Æquator, the predominant Wind is between the Eaſt and North-Eaſt, and to the Southwards thereof there is a conſtant ſteady Gale between the Eaſt and South-Eaſt, and that on both ſides the Line with ſo much conſtancy, that they ſcarce ever need to attend the Sails, and Strength, that it is rare to fail of croſſing this vaſt Ocean in ten Weeks time, which is about 130 Miles *per diem*; beſides 'tis ſaid that Storms and Tempeſts are never known in theſe parts: So that here is the very beſt of Sailing; no want of a freſh fair Wind, and yet no danger of having too much: Wherefore ſome have thought it might be as ſhort a Voyage to *Japan* and *China*, to go by the Streights of *Magellan*, as by the *Cape* of *Good-Hope*.

The limits of theſe general Winds are alſo much the ſame as in the *Atlantick* Sea, *viz*. about the thirtieth Degree of Latitude on both ſides; for the *Spaniards* homewards bound from the *Manhila*'s, always take the advantage of the Southerly *Monſoon*, blowing there in the Summer Months, and run up to the Northwards of that Latitude, as high as *Japan*, before they meet with variable Winds, to ſhape their Courſe to the Eaſtwards. And *Schooten* and others that have gone about by the *Magellan* Streights, have found the limits of S. E.

Winds, much about the ſame Latitude to the Southwards; beſides a farther *Analogy* between the Winds of this Ocean, and the *Æthiopick*, appears in that, upon the Coaſt of *Peru*, they are always much Southerly, like as they are found near the Shores of *Angola*.

Thus far Matter of Fact, wherein if the information I have receiv'd be not in all parts Accurate, it has not been for want of inquiry from thoſe I conceiv'd beſt able to inſtruct me; and I ſhall take it for a very great Kindneſs if any Maſter of a Ship, or other Perſon, well inform'd of the Nature of the Winds, in any of the aforementioned parts of the World, ſhall pleaſe to communicate their Obſervations thereupon; ſo that what I have here Collected may be either confirm'd or amended, or by the addition of ſome material Circumſtances enlarg'd. It is not the work of one, nor of few, but of a multitude of Obſervers, to bring together the experience requiſite to compoſe a perfect and compleat Hiſtory of theſe Winds; however I am not much doubtful that I have err'd in, or omitted any of the principal Obſervables, whatever leſſer particulars may have eſcaped my knowledge.

To help the Conception of the Reader in a manner of ſo much difficulty, I believ'd it neceſſary to adjoin a Scheme, *Plate* 2. ſhewing at one view all the various Tracts and Courſes of theſe Winds; whereby 'tis poſſible the thing may be better underſtood, than by any verbal Deſcription whatſoever.

The Limits of theſe ſeveral Tracts are deſigned every where by prickt Lines, as well in the *Atlantick* and *Æthiopick*, where they are the boundaries of the Trade and variable Winds, as in the *Indian* Ocean, where they alſo ſhew the extent of the ſeveral *Monſoons.* I could think of no better way to deſign the courſe of the Winds on the Map, than by drawing rows of ſtroaks in the ſame Line that a Ship would move going always before it; the ſharp end of each little ſtroak pointing out that part of the Horizon, from whence the Wind continually comes; and where there are *Monſoons*, the rows of the ſtroaks run alternately backwards and forwards, by which means they are thicker there than elſewhere. As to the great South Sea, conſidering its vaſt extent, and the little Variety there is in its Winds, and the great *Analogy* between them, and thoſe of the *Atlantick* and *Æthiopick* Oceans; beſides that the greateſt part thereof is wholly unknown to us; I thought it unneceſſary to lengthen the Map therewith.

In the foregoing Hiſtory are contained ſeveral Problems, that merit well the Conſideration of our acuteſt Naturaliſts, both by reaſon of the conſtancy of the Effect, and of the immenſe Extent thereof; near half the Surface of the Globe being concerned. The chief of theſe Problems are, 1. Why theſe Winds are perpetually from the Eaſt in the *Atlantick* and *Æthiopick*, as likewiſe in the *Pacifick* Ocean, between the Latitudes of 30 North and South. 2. Why the ſaid Winds extend no farther with Conſtancy than to the Latitudes of 30 *deg.* 3. Why there ſhould be a conſtant South-weſterly Wind upon and near the Coaſt of *Guinea.* 4. Why in the North-part of the *Indian* Ocean the Winds, which for one half year do agree with thoſe of the other two Oceans, ſhould change in the other half Year, and blow from the oppoſite

Points; whilſt the Southern part of that Ocean follows the General Rule, and has perpetual Winds about S. E. 5. Why in theſe General Trade-Winds it ſhould be always true, that to the Northward of the *Æquator* it is inclined to the Northwards of the Eaſt; and in South Latitudes, to the Southward thereof. 6. Why in theſe Seas of *China* there ſhould be ſo great an Inclination from the Eaſt to the North, more than elſewhere; with many more, which it would be much eaſier to propoſe than anſwer.

But leſt I ſhould ſeem to propoſe to others, difficulties which I have not thought worth my own time and Pains, take here the reſult of an earneſt Endeavour after the true reaſon of the aforeſaid *Phænomena*, wherein if I am not able to account for all Particulars, yet 'tis hoped the Thoughts I have ſpent thereon, will not be judged wholly loſt, by the curious in Natural Enquiries.

Wind is moſt properly defined to be the Stream or Current of the Air, and where ſuch a Current is perpetual and fixt in its courſe, 'tis neceſſary that it proceed from a permanent unintermitting Cauſe. Wherefore ſome have been inclined to propoſe the diurnal *Rotation* of the Earth upon its *Axis*, by which, as the *Globe* turns Eaſtwards, the looſe and *fluid* Particles of the Air, being ſo exceeding light as they be, are left behind, ſo that in reſpect of the Earths *Surface* they move Weſtwards, and become a conſtant Eaſterly Wind. This Opinion ſeems confirmed, for that theſe Winds are found only near the *Æquinoctial*, in thoſe Parallels of Latitude where the diurnal Motion is ſwifteſt; and I ſhould readily aſſent to it, if the conſtant Calms in the *Atlantick* Sea, near the *Æquator*;

the Weſterly Winds near the Coaſt of *Guiny*; and the *Periodical* Weſterly *Monſoons* under the *Æquator* in the *Indian* Seas,did not declare inſufficiency of that *Hypotheſis*. Beſides the Air being kept to the Earth by the Principle of *Gravity*, would acquire the ſame degree of *Velocity* that the Earths *Surface* moves with, as well in reſpect of the diurnal *Rotation*, as of the Annual about the Sun, which is about thirty times ſwifter.

It remains therefore to ſubſtitute ſome other cauſe, capable of producing a like conſtant effect, not liable to the ſame Objections, but agreable to the known Properties of the Elements of Air and Water, and the Laws of the Motion of fluid Bodies. Such an one is, I conceive, the Action of the Sun Beams upon the Air and Water, as he paſſes every day over the Oceans, conſidered together with the Nature of the Soil, and Situation of the adjoining Continents: I ſay therefore, firſt, that according to the Laws of *Staticks*, the Air which is leſs rarified or expanded by heat, and conſequently more ponderous, muſt have a Motion towards thoſe parts thereof, which are more rarified, and leſs ponderous, to bring it to an *Æquilibrium*; and ſecondly, that the Preſence of the Sun continually ſhifting to the Weſtwards, that part towards which the Air tends, by reaſon of the Rarifaction made by his greateſt *Meridian* Heat, is with him carried Weſtward, and conſequently the tendency of the whole Body of the lower Air is that way.

Thus a general Eaſterly Wind is formed, which being impreſſed upon all the Air of a vaſt Ocean, the Parts impel one the other, and ſo keep moving till the next return of the Sun, whereby ſo much of the Motion as was loſt, is again reſtored, and thus the Weſterly Wind is made perpetual.

From the ſame Principle it follows, that this Eaſterly Wind ſhould on the North-ſide of the *Æquator*, be to the Northwards of the Eaſt, and in South Latitudes to the Southwards thereof; for near the *Line*, the Air is much more rarified, than at a greater diſtance from it; becauſe of the Sun twice in a Year Vertical, and at no time diſtant above 23 deg. and a half; at which diſtance the Heat, being as the Sine of the Angle of Incidence, is but little ſhort of that of the perpendicular Ray. Whereas under the Tropicks, though the Sun ſtay long Vertical, yet he is as long 47 deg. off; which is a kind of Winter, wherein the Air ſo cools, as that the Summer-heat cannot warm it to the ſame degree with that under the Æquator. Wherefore the Air to the Northwards and Southwards, being leſs rarified than that in the middle, it follows, that from both ſides it ought to tend towards the Æquator: This Motion compounded with the former Eaſterly Wind anſwers all the *Phænomena* of the general Trade-winds; which, if the whole Surface of the Globe were Sea, would undoubtedly blow all round the World, as they are found to do in the *Atlantick* and *Æthiopick* Oceans.

But ſeeing that ſo great Continents do interpoſe and break the continuity of the Oceans, regard muſt be had to the Nature of the Soil, and the Poſition of the high Mountains, which I ſuppoſe the two principal Cauſes of the ſeveral Variations of the Winds, from the former general Rule: For if a Country lying near the Sun, prove to be flat, ſandy, low Land, ſuch as the Deſarts of *Lybia* are uſually reported to be, the Heat occaſioned by the Reflection of the Suns Beams, and the retention thereof in the Sand, is incredible to thoſe that have not felt it; whereby the Air being exceedingly rarified, it is neceſſary that the cooler and more denſe Air ſhould run thitherwards to reſtore the *Æquilibrium:* This I take to be the cauſe, why near the Coaſt of *Guinea* the Wind always ſets in upon the Land, blowing Weſterly inſtead of Eaſterly, there being ſufficient reaſon to believe, that the Inland Parts of *Africa* are prodigiouſly hot, ſince the Northern Borders thereof were ſo intemperate, as to give the Ancients cauſe to conclude, that all beyond the *Tropick* was made inhabitable by exceſs of Heat: From the ſame cauſe it happens, that there are ſo conſtant Calms in that part of the Ocean, called the *Raines*, (deſcribed in the 7th Remark on the *Atlantick* Sea) for this Tract being placed in the middle, between the Weſterly Winds blowing on the Coaſt *Guinea*, and the Eaſterly Trade-winds, blowing to the Weſtwards thereof, the tendency of the Air here, is indifferent to either, and ſo ſtands in *Æquilibrio* between both; and the weight of the incumbent Atmoſphere being diminiſhed by the continual contrary Winds blowing from hence, is the reaſon that the Air here holds not the copious Vapour it receives, but lets it fall into frequent Rains.

But as to the cool and denſe Air, by reaſon of its greater Gravity, preſſes upon the hot and rarified, 'tis demonſtrative that this latter muſt aſcend in a continued ſtream as faſt it rarifies; and that being aſcended, it muſt diſperſe it ſelf to preſerve the *Æquilibrium*; that is, by a contrary Current, the upper Air muſt move from thoſe Parts where the greateſt Heat is: So by a kind of Circulation, the North-Eaſt Trade Wind below, will be attended with a South-Weſterly above, and the South Eaſterly with with a North-Weſt Wind above; that this is more than a bare conjecture, the almoſt inſtantaneous change of the Wind to the oppoſite Point, which is frequently found in paſſing the limits of the Trade-winds, ſeems to aſſure us; but that which above all confirms this *Hypotheſis* is the *Phænomenon* of the *Monſoons*, by this means moſt eaſily ſolved, and without it hardly explicable.

Suppoſing therefore ſuch a Circulation as above, 'tis to be conſidered that to the Northward of the *Indian* Ocean there is every where Land within the uſual limit of the Latitude of 30. *viz. Arabia*, *Perſia*, *India*, *&c.* which for the ſame reaſon as the *Mediterranean* Parts of *Africa*, are ſubject to unſufferable Heats when the Sun is to the North, paſſing nearly Vertical; but yet are temperate enough when the Sun is removed towards the other *Tropick*; becauſe of a ridge of Mountains at ſome diſtance within the Land, ſaid to be frequently in Winter covered with Snow, over which the Air, as it paſſes, muſt needs be much chilled. Hence it comes to paſs that the Air coming according to the general Rule, out of the *N. E.* in the *Indian* Seas, is ſometimes hotter, ſometimes colder, than that which by this Circulation is returned out of the *S. W.* and by conſequence, ſometimes the under Current or Wind is from the N. E. ſometimes from the S. W.

That this has no other Cauſe, is clear from the times wherein theſe Winds ſet in, *viz.* in *April*, when the Sun begins to warm thoſe Countries to the North, the S. W. *Monſoon* begins, and blows during the Heats till *October*; when the Sun being retir'd, and all things growing cooler Northward, and the Heat increaſing to the South, the North-Eaſt Winds enter and blow all the Winter till *April* again. And it is undoubtedly from the ſame Principle that to the Southwards of the Æquator, in part of the *Indian* Ocean, the North-Weſt Winds ſucceed the South-Eaſt, when the Sun draws near the *Tropick* of *Capricorn*; but I muſt confeſs, that in this latter occurs a difficulty, not well to be accounted for, which is, why this Change of the *Monſoons* ſhould be any more in this Ocean, than in the ſame Latitudes in the *Æthiopick*, where there is nothing more certain than a S. E. Wind all the Year.

'Tis likewiſe very hard to conceive why the limits of the Trade-Wind ſhould be fixt, about the thirtieth Degree of Latitude all round the Globe; and that they ſhould ſo ſeldom tranſgreſs or fall ſhort of thoſe bounds; as alſo that in the *Indian* Sea, only the Northern Part ſhould be ſubject to the changeable *Monſoons*, and in the Southern there be a conſtant S. E.

Theſe are Particulars that merit to be conſider'd more at large, and furniſh a ſufficient Subject for a juſt Volume, which will be a very commendable Task for ſuch, who being uſed to Philoſophick Contemplation, ſhall have leaſure to apply their ſerious Thoughts about it.

A

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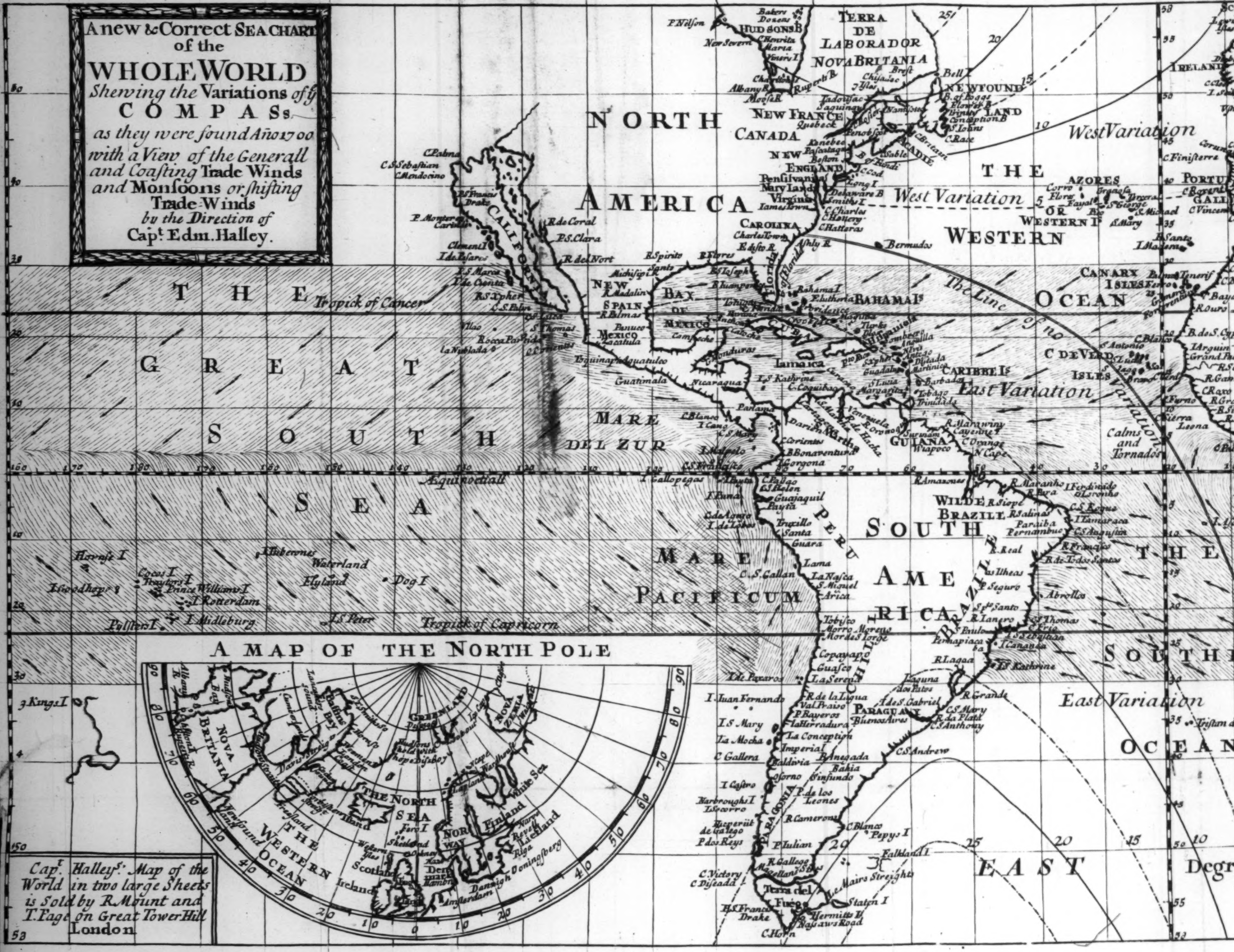

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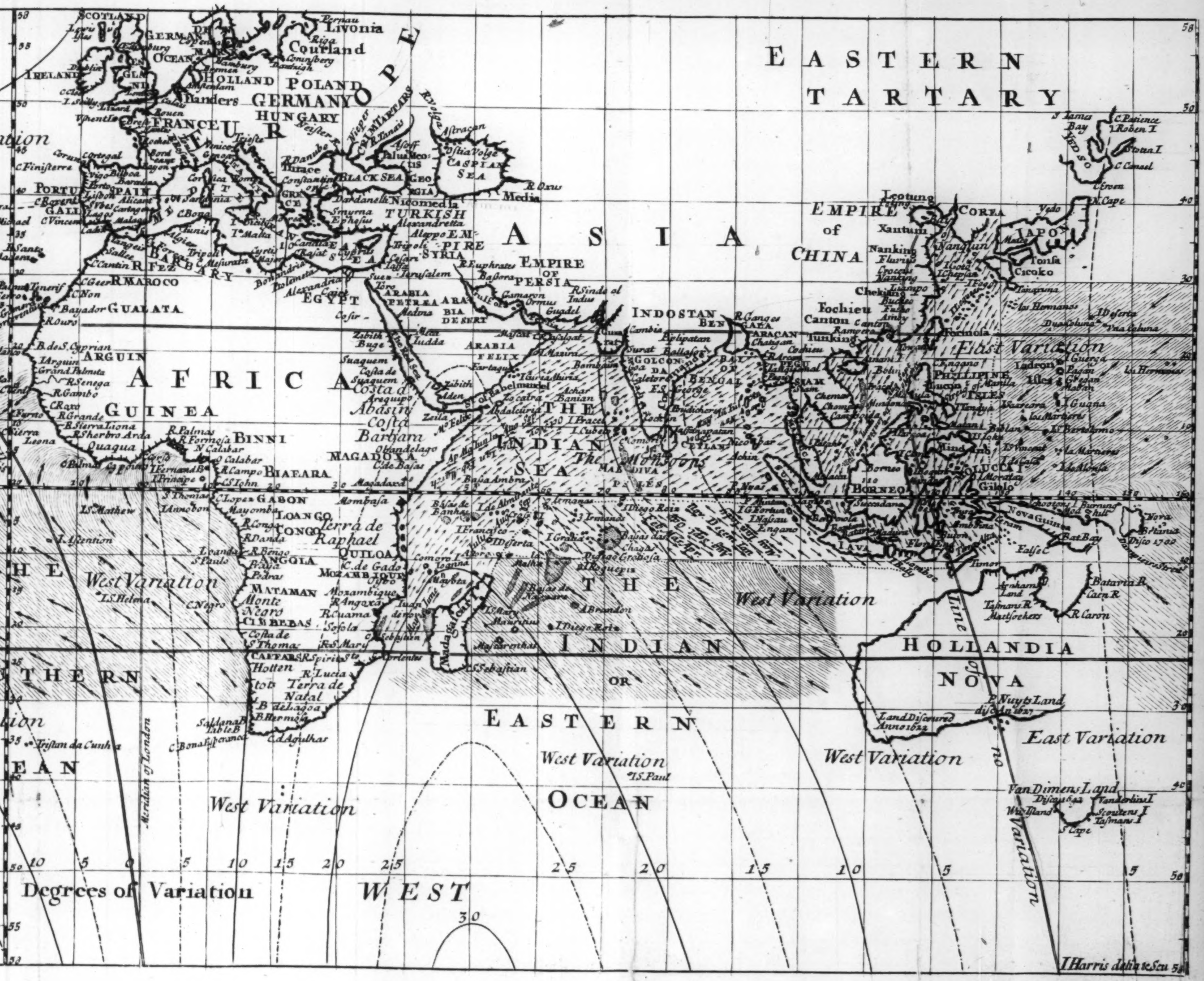
EASTERN TARTARY
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IRELAND
GERMAN OCEAN
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GERMANY
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Tripoli
I. Malta
Candia
Cyprus
BARBARY
MAROCO
R. Fez
C. Cantin
C. Geer
C. Non
Tenerif
Bayador
GUALATA
Thrace
Constantinople
BLACK SEA
CRIM TARTARS
Asoff
Palus Meotis
Astracan
Volga
Ostia Volge
CASPIAN SEA
R. Oxus
Media
Dardanelles
Nicomedia
Smyrna
Ephesus
TURKISH EMPIRE
Alexandretta
Aleppo
SYRIA
Jerusalem
R. Euphrates
Bassora
EMPIRE OF PERSIA
Ormus
Gombroon
R. Sinde ol Indus
Guadel
Alexandria
EGYPT
Cairo
Suez
Tor
ARABIA PETRÆA
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ARGUIN
B. de S. Cyprian
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C. Lopez
Mayomba
LOANGO
CONGO
R. Congo
R. Danda
Loanda
S. Pauls
ANGOLA
Terra de Raphael
Mombasa
Magadoxa
MAGADOXA
Quiloa
C. de Gado
MOZAMBIQUE
Mozambique
Costa d' Abasin
Costa Barbara
Zeila
C. Guardafui
Melinda
Brava
Monte Negro
MATAMAN
CIMBEBAS
C. Negro
Costa de S. Thomas
CAFFARS
Hottentots
R. Spirito
R. Lucia
Terra de Natal
B. de Lagoa
Saldana B.
Table B.
C. Bona Esperanza
C. des Agulhas
Madagascar
Comoro I.
Mauritius
Mascarenhas
I. Diego Rodrigues
S. Sebastian
I. S. Mary
I. Brandon
I. S. Mathew
I. Ascension
I. S. Helena
Tristan da Cunha
I. S. Paul
INDOSTAN
BENGALA
R. Ganges
ARACAN
PEGU
SIAM
Cambaya
Surat
Bombaim
Golconda
Bay of Bengal
Maldiva Isles
Ceylan
Cochin
Comorin
Achin
Nicobar
THE INDIAN SEA
The Monsoons
THE INDIAN OR EASTERN OCEAN
EMPIRE of CHINA
Leotung
Peking
Xantum
Nanking
Canton
Fochieu
Chekiang
Tunking
Cochin
Formosa
COREA
IAPON
Jedo
Tonsa
Cicoko
Philipine Isles
Manila
Lucon
Ladrones Isles
Borneo
BORNEO
Succadana
Sumatra
Java
Moluccas
Gilolo
Celebes
Timor
Nova Guinea
NOVA BRITANIA Discov. 1700
New Guinea
HOLLANDIA NOVA
P. Nuyts Land disc. An. 1627
Land Discovered Anno 1622
Van Dimens Land Discov. 1642
Carpentaria
East Variation
West Variation
Line of no Variation
Meridian of London
Degrees of Variation
WEST
10 5 0 5 10 15 20 25 25 20 15 10 5 5
30
I Harris delin. et Sculp.

A Diſcourſe of the Rule of the Decreaſe of the height of the Mercury *in the Barometer, according as Places are elevated above the Surface of the Earth; with an Attempt to diſcover the true Reaſon of the Riſing and Falling of the* Mercury, *upon Change of Weather. By* Edm. Halley.

THE Elaſtick Property of the Air has been long ſince made out, by Experiments before the Royal Society and elſewhere; and the Reſiſtance of its Spring is found to be nearly equal to the Weight or Force that compreſſes it; as alſo, that the Spaces the ſame Air occupies, under differing Preſſures, are reciprocally as thoſe Preſſures: It has been ſhown likewiſe by undoubted Experiment, that the ſpecifick Gravity of the Air, near the Earth's Surface to that of Water, was once as 1 to 840; again as 1 to 852; and a third time, in a very large Veſſel holding 10 Gallons, as 1 to 860; all which, conſidering the difficulty of the Experiment, agree well enough, the Mercury ſtanding at all thoſe times about 29 Inches $\frac{1}{4}$: But by reaſon 'twas Summer-weather, and conſequently the Air rarified, when all theſe were tried, we may without ſenſible Error ſay in round numbers, that the Barometer ſtanding at 30 Inches, and in a mean State of Heat and Cold, the ſpecifick Gravity of the Air to Water, is as 1 to 800. By the the like Trials the Weight of Mercury to Water, is as 13½ to 1, or very near it; ſo that the weight of Mercury to Air, is as 10800 to 1; and a Cylinder of Air of 10800 Inches or 900 Feet, is equal to an Inch of Mercury; and were the Air of an equal denſity like Water, the whole Atmoſphere would be no more than 5, 1 miles high, and in the Aſcent of every 900 Feet the Barometer would ſink an Inch. But the Expanſion of the Air increaſing in the ſame proportion as the incumbent weight of the Atmoſphere decreaſes; that is, as the Mercury in the Barometer ſinks, the upper Parts of the *Air* are much more rarified than the lower, and each Space anſwering to an Inch of Quickſilver grows greater and greater; ſo that the Atmoſphere muſt be extended to a much greater height. Now, upon theſe Principles, to determine the height of the *Mercury* at any aſſigned height in the *Air*; and *e contra*, having the height of the *Mercury* given, to find the height of the Place where the *Barometer* ſtands, are Problems not more difficult than curious; and which I thus reſolve.

The Expanſions of the *Air* being reciprocally as the heights of the *Mercury*, it is evident, that by the help of the Curve of the *Hyperbola* and its *Aſymptotes*, the ſaid Expanſions may be expounded to any given height of the *Mercury*: For by the 65th *Prop. lib. 2. Conic. Mydorgii, the Rectangles, ABCE, AKGE, ALDE, &c.* (in *Plate* 1. *Fig.* 4.) are always equal, and conſequently the ſides, *C B*, *G K*, *L D*, *&c.* are reciprocally as the ſides *A B*, *A K*, *A L*, *&c.* If then the Lines *A B*, *A K*, *A L*, be ſuppoſed equal to the heights of the *Mercury*, or the preſſures of the Atmoſphere, the Lines *C B*, *K G*, *L D*, anſwering thereto, will be as the Expanſions of the *Air* under thoſe Preſſures, or the bulks that the ſame quantity of *Air* will occupy; which Expanſions being taken infinitely many, and infinitely little, (according to the Method of Indiviſibles) their Summ will give the Spaces of Air between the ſeveral heights of the *Barometer*; that is to ſay, the Summ of all the Lines between *C B* and *K G*, or the *Area C B K G*, will be proportioned to the diſtance or ſpace intercepted between the Levels of two Places in the Air, where the *Mercury* would ſtand at the heights repreſented by the Lines *A B*, *A K*; ſo then the Spaces of Air anſwering to equal Parts of *Mercury* in the *Barometer*, are as the *Area's C B K G*, *G K L D*, *D L F M*, *&c.* Theſe *Area's* again are, by the Demonſtration of *Gregory* of St. *Vincent*, proportionate to the *Logarithms* of the Numbers expreſſing the *Rationes* of *A K* to *A B*, of *A L* to *A K*, of *A M* to *A L*, *&c.* So then by the common Table of *Logarithms*, the height of any Place in the *Atmoſphere*, having any aſſigned height of the *Mercury* may moſt eaſily be found: For the Line *C B* in the *Hyperbola*, whereof the *Area's* deſign the *Tabular Logarithms*, being 0, 0144765; 'twill be, as 0. 0144765, to the difference of the *Logarithms* of 30, and any other leſſer Number, for 900 Feet or the Space anſwering to an Inch of *Mercury*, if the Air were equally preſt with 30 Inches of *Mercury*, and every where alike, to the height of the *Barometer* in the *Air*, where it

will

will ſtand at that leſſer number of Inches: And by the Converſe of this Proportion may the height of the *Mercury* be found, having the Altitude of the Place given. From theſe Rules I deriv'd the following Tables.

A Table ſhewing the Altitude, to given heights of the Mercury.

Inch.	Feet.
30	0
29	915
28	1862
27	2844
26	3863
25	4922
20	10947
15	18715
10	29662
5	48378
1	91831
0. 5	110547
0 25	129262
0. 1	29 mil. or 154000
0. 01	41 mil. or 216169
0. 001	53 mil. 278338

A Table ſhewing the heights of the Mercury, *at given Altitudes.*

Feet	Inch
0	30 00
1000	28 91
2000	27 86
3000	26 85
4000	25 87
5000 feet	24 93
1 mile	24 67
2	20 29
3	16 68
4	13 72
5	11 28
10	4 24
15	1 60
20	0 95
25	0 23
30	0 08
40	0 012

UPON theſe Suppoſitions it appears, that at the height of 41 Miles the *Air* is ſo rarified, as to take up 3000 times the Space it occupies here, and at 53 Miles high it would be expanded above 30000 times; but it's probable that the utmoſt Power of its Spring cannot exert it ſelf, to ſo great an Extenſion, and that no part of the *Atmoſphere* reaches above 45 Miles from the Surface of the Earth.

This ſeems confirmed from the Obſervations of the *Crepuſculum*, which is obſerv'd commonla to begin and end when the Summ is about 18 degrees below the Horizon; for ſuppoſing the *Air* to reflect light from its moſt rarified Parts, and that as long as the Sun illuminates any of its *Atoms*, they are viſible to an Eye not intercepted by the Curvity of the Earth, it will follow from *Fig*.5. *Plate* 1. that the proportion of the height of the whole *Air*, to the Semi-diameter of the Earth, is much about, as 1 to 90, or as the exceſs of the *Secant* of about 8½ degrees to the *Radius*. For if *E* be the Eye of the Obſerver, *S* a Place where the Sun ſets at the end of Twilight in *E*, and the Arch *E C S*, or *T C A* be found 18 degrees, the exceſs of the *Secant* of half thereof *E C H*, would be the height of the *Air*, *viz*. *G H*: But the Beam of the Sun *A S H*, and the Viſual Ray *E H*, do each of them ſuffer a Refraction of about 32 or 33 Minutes, whereby being bent inwards from *H* towards *G*, the height of the *Air* need not be ſo great as if they went ſtreight; and having from the Angle *E C S* taken the double Refraction of the *Horizontal Ray*, the half of the Remainder will be 8½ degrees *Circiter*, whoſe *Secant* being 10 111, it follows that as 10000 to 111, ſo the Semi-diameter of the Earth ſuppoſed 4000 Miles, to 44, 4 Miles; which will be the height of the whole *Air*, if the Places *E*, *S*, whoſe viſible Portions of the *Atmoſphere* *E R Z H*, and *S H K B* juſt touch one the other, be 18 degrees aſunder.

At this height the *Air* is expanded into above 3000 times the ſpace it occupies here, and we have ſeen the Experience of condenſing it into the 60th part of the ſame Space; ſo that it ſhould ſeem, that the Air is a Subſtance capable of being compreſſed into the 180000th part of the Space it would naturally take up, when free from preſſure. Now what Texture or Compoſition of Parts ſhall be capable of this great Expanſion and Contraction, ſeems a very hard Queſtion; and which, I ſuppoſe, is ſcarce ſufficiently accounted for, by comparing it to Wool, Cotton, and the like ſpringy Bodies.

Hitherto I have only conſider'd the *Air* and *Atmoſphere*, as one unalter'd Body, as having conſtantly at the Earth's Surface the 800th part of the weight of Water, and being capable of Rarefaction and Condenſation *in infinitum*; neither of which *Hypotheſes* are rigidly true: For here in *England* it's notoriouſly known, that the weight of the whole *Atmoſphere* is various, being counterpoiſed ſometimes by $28\frac{1}{2}$ Inches of *Mercury*, and at other times by no leſs than $30\frac{1}{2}$; ſo that the under parts being preſſed by about a 15th part, leſs weight, the *ſpecifick* Gravity of the *Air* upon that ſcore will ſometimes be a 15th part lighter than another; beſides Heat and Cold does very conſiderably dilate and contract the Air, and conſequently alter its Gravity; to which add the mixture of *Effluvia*, or ſteams ariſing from almoſt all Bodies,

dies, which aſſimulating into the Form of Air are kept ſuſpended therein, as Salts diſſolv'd in Liquors, or Mettles in corroding *Menſtrua*; which Bodies being all of them very much heavier than *Air*, their Particles by their Admixture muſt needs encreaſe the weight of that *Air* they lie incorporated withal, after the ſame manner as melted Salts do augment the ſpecifick Gravity of Water. The other Conſideration is, that the Rarefaction and Condenſation of the *Air* is not preciſely according to the proportion here laid down; for the Experiment very nearly agrees thereto, as may be ſeen in the 58th Chapter of *Mr. Hook's Micorgraphy*; yet are the Condenſations not poſſible beyond certain degrees: For being compreſſed into an 800th part of the Space it takes up here, its conſiſtence would be equally denſe with that of Water; which yields not to any force whatſoever, as hath been found by ſeveral Experiments tried here, and at *Florence*, by the *Academia del Cimento*. Nor can the Rarefaction proceed *in infinitum*; for ſuppoſing the Spring whereby it dilates it ſelf, occaſion'd by what Texture of Parts you pleaſe, yet muſt there be a determinate Magnitude of the natural State of each Particle, as we ſee it is in Wool and the like, whoſe Bodies being compreſſable into a very ſmall Space, have yet a determinate bulk which they cannot exceed, when free'd from all manner of Preſſure.

Theſe Objections being true, do diſturb the Geometrical Accuracy of theſe Concluſions, drawn from the ſpecifick Gravity of the *Air* obſerv'd at any time; but the Method here ſhewn will compute by a like Calculation, the heights of the *Quick-ſilver*, and the Rarefactions

of

of the *Air* from any aſſigned height of the *Barometer* at the Earth's Surface, and any ſpecifick Gravity given. As to the Condenſation and Rarefaction by Heat and Cold, and the various mixture of Aqueous and other Vapours, theſe two Objections ſeem generally to compenſate each other; for when the Air is rarified by Heat, they are raiſed moſt copiouſly; ſo that tho' the *Air* properly ſo called, be expanded, and conſequently lighter, yet the *Interſtices* thereof being crouded full of Vapours of much heavier Matters, bulk for bulk, the weight of the *Compoſitum* may continue much the ſame; at leaſt a moſt curious Experiment made by the Ingenious Mr. *John Caſwell*, of *Oxford*, upon the top of *Snowdon* Hill, in *Caernarvanſhire*, ſeems to prove, that the firſt Inches of *Mercury* have their Portions of *Air* near enough to what I now determine: For the height of the Hill being 1240 Yards, or very near it, he found the *Mercury* to have ſubſided to 25, 6 Inches or 4 Inches below the mean Altitude thereof at the Level of the Sea, (which is a greater difference than has been found in any of our former Experiments,) and the Space anſwering to 4 Inches, by my Calculation, ſhould be 1288 Yards; and it agrees as well with the Obſervations in the Appendix to Mr. *Paſcall*'s Book, *del' Equilibre des Liqueurs*, made on the high Hill in *Auvergne*, call'd *le puy de Domme*. So that the Rarefaction and Vapours ſeem not to have altered conſiderably, the Gravity of the under Parts of the *Air*; and much above the height where theſe Experiments were made, do *few* Vapours aſcend, and the Cold is ſuch that the Snow lies continually, ſo that for the more elevated Parts of the Sphere of *Air*, there is much leſs Reaſon to doubt.

But now we have had occaſion to mention the difference there is between the height of the *Mercury* at one time, from the height thereof at another, it may not be unacceptable to offer at ſome Reaſons for the ſaid difference; which, at leaſt to my ſelf, ſeem to have ſome appearance of Truth. *Firſt*, then it's undoubtedly demonſtrable, that the height of the Cylinder of *Mercury* is equal to the weight of the whole incumbent *Air*, and conſequently that that whole is ſometimes a fifteenth more than at other times; which cannot otherwiſe be, but by the acceſs of new Matter when 'tis heavy, and its diminution when 'tis light; that *Hypotheſis* therefore that ſhews how the *Air* ſhall be encreaſed or diminiſhed, in any particular place, will give a Reaſon for the greater and leſſer height of the *Mercury* in the *Baroſcope*: But to direct us in the choice of the ſeveral Cauſes, which may be aſſigned for the Increaſe and Decreaſe of the *Air*, 'twill not be unneceſſary to enumerate ſome of the principal Obſervations made upon the *Barometer*, moſt whereof are ſufficiently known already to all thoſe that are curious in theſe Matters.

The *Firſt* is, that in calm Weather when the *Air* is inclined to Rain, the *Mercury* is commonly low.

2. That in ſerene good ſettled Weather the *Mercury* is generally high.

3. That upon very great Winds, tho' they be not accompanied with Rain, the *Mercury* ſinks loweſt of all, with relation to the Point of the Compaſs the Wind blows upon.

4. That *cæteris paribus* the greateſt heights of the *Mercury* are found upon Eaſterly and North-Eaſterly Winds.

5. That in calm froſty Weather the *Mercury* generally ſtands high.

6. That after very great Storms of Wind, when the *Quickſilver* has been low, it generally riſes again very faſt.

7. That the more Northerly places have greater alterations of the *Baroſcope* than the more Southerly.

8. That within the *Tropicks* and near them, thoſe Accounts I have had from others, and my own Obſervation at St. *Helena* make very little or no Variation of the height of the *Mercury* in all weathers. Now that Theory that can well account for all theſe appearances, will, in all probability, approach nearer the true cauſe of the *Barometers* Variations, than any thing hitherto afforded; and ſuch an one I am bound to believe, is that which I here lay down with ſubmiſſion to better Judgments.

I conceive that the principal Cauſe of the riſe and fall of the *Mercury*, is from the variable Winds, which are found in the *Temperate Zones*, and whoſe great unconſtancy here in *England* is moſt notorious. I ſhall not at preſent inquire into the cauſe of its uncertainty, but the Matter of Fact being moſt undoubted, the Legitimate Conſequences thereof muſt be allow'd me, let it proceed from what it will.

A ſecond Cauſe is the uncertain Exhalation and Præcipitation of the Vapourslodging in the Air, whereby it comes to be at one time much more crowded than at another, and conſequently heavier; but this latter in a great meaſure depends upon the former. Now from theſe Principles I ſhall endeavour to explicate the ſeveral *Phænomena* of the *Barometer*, taking them in the ſame order I laid them down.

1. *Why in Calm Weather the* Air *being inclin'd to Rain, the* Mercury *is commonly low?* I Anſwer, That the *Mercury*'s being low, inclines it to Rain; for the Air being light, the Vapours are no longer ſupported thereby, being become ſpecifically heavier than the Medium wherein they floated; ſo that they deſcend towards the Earth, and in their fall meeting with other aqueous Particles, they incorporate together, and form little drops of Rain; but the *Mercury*'s being at one time lower than another, is the effect of two contrary Winds blowing from the place whence the *Barometer* ſtands; whereby the *Air* of that place is carried both ways from it, and conſequently the imumbent Cylinder of *Air* is diminiſh'd, and accordingly the *Mercury* ſinks; as for inſtance, if in the *German Ocean* it ſhould blow a Gale of Weſterly Wind, and at the ſame time an Eaſterly Wind in the *Iriſh-Sea*; or if in *France* it ſhould blow a Southerly Wind, and in *Scotland* a Northern; it muſt be granted me, that That part of the *Atmoſphere* impendent over *England*, would thereby be exhauſted and attenuated, and the *Mercury* would ſubſide, and the Vapours which before floated in thoſe parts of the *Air* of equal

Gravity with themſelves, would ſink to the Earth.

2. *Why in ſerene good ſettled weather the* Mercury *is generally high.* To this I Anſwer, That the greater height of the *Barometer*, is occaſion'd by two contrary Winds blowing *towards* the place of Obſervation, whereby the *Air* of other places is brought thither and accumulated; ſo that the incumbent Cylinder of Air being encreaſed both in height and weight, the *Mercury* preſs'd thereby muſt needs riſe and ſtand high, as long as the Winds continue ſo to blow; and then the Air being ſpecifically heavier, the Vapours are better kept ſuſpended, ſo that they have no inclination to Præcipitate and fall down in Drops, which is the reaſon of the ſerene good Weather, which attends the greater heights of the *Mercury*.

3. *Why upon very great Winds or Storms, though accompanied with no Rain, the* Mercury *ſinks loweſt of all, with relation to the Point of the Compaſs upon which the Wind blows.* This is caus'd by the very rapid Motion of the *Air* in theſe Storms; for the Tract or Region of the Earths Surface, wherein theſe Winds rage, not extending all round the Globe, that ſtagnant *Air* which is left behind, as likewiſe that on the ſides, cannot come in ſo faſt as to ſupply the Evacuation made by ſo ſwift a Current; ſo that the Air muſt neceſſarily be attenuated, when and where the ſaid Winds continue to blow, and that more or leſs according to their violence; add to which, that the *Horizontal* Motion of the *Air* being ſo quick as it is, may in all probability take off ſome part of the perpendicular

preſſure thereof; and the great agitation of its Particles, is the Reaſon why the Vapours are diſſipated and do not condenſe into Drops, ſo as to form Rain, otherwiſe the natural Conſequence of the *Airs* Rarefaction.

4. *Why* cæteris paribus *the* Mercury *ſtands higheſt upon an Eaſterly or North-Eaſterly Wind.* This happens becauſe that the great *Atlantick Ocean* on this ſide the thirty fifth Degree of North Latitude, the Weſterly and South-Weſterly Winds blow almoſt always *Trade*; ſo that whenever here the Wind comes up at Eaſt and North-Eaſt, 'tis ſure to be checked by a contrary Gale, as ſoon as it reaches the *Ocean*; wherefore, according to what is made out in our ſecond Remark, the *Air* muſt needs be heaped over this Iſland; and conſequently the *Mercury* muſt ſtand high, as often as theſe Winds blow. This holds true in this Country, but is not a general Rule for others, where the Winds are under different Circumſtances; and I have ſometimes ſeen the *Mercury* here as low as twenty nine Inches, upon an Eaſterly Wind, but then it blows exceeding hard, and ſo comes to be accounted for by what was obſerv'd upon the third Remark.

5. *Why in calm Weather the* Mercury *generally ſtands high.* The cauſe hereof is, as I conceive, that it ſeldom freezes but when the Winds come out of the Northern and North-Eaſtern Quarters, or at leaſt unleſs thoſe Winds blow at no great diſtance of; for the Northern Parts of *Germany*, *Denmark*, *Sweeden*, *Norway*, and all that Tract from whence North-Eaſtern Winds come, are ſubject to almoſt con-

tinual Froſt all the Winter; and thereby the lower Air is very much condens'd, and in that State is brought hitherwards by theſe Winds, and being accumulated by the oppoſition of the Weſterly Wind blowing in the Ocean, the *Mercury* muſt needs be preſt to a more than ordinary height, and as a concurring Cauſe, the ſhrinking of the lower parts of the *Air* into leſſer room by cold, muſt needs cauſe a deſcent of the upper parts of the Atmoſphere to reduce the Cavity made by this contraction to an *Æquilibrium*.

6. Why after very great Storms of Wind, when the Mercury *has been very low, it generally riſes again very faſt.* This I have frequently obſerv'd, and once found it riſen an Inch and a half in leſs than ſix Hours, after a long continu'd Storm of South-Weſt Wind. This ſeems to be occaſion'd by the ſuddain Acceſſion of new *Air* to ſupply the great Evacuation which ſuch continu'd Storms make thereof, in thoſe places whence they happen (as in the third Remark) and by the Recoile of the Air, after the force ceaſes that impell'd it; and the Reaſon why the *Mercury* riſes ſo faſt, is becauſe the Air being very much rarify'd beyond its mean denſity, the Neighbouring *Air* runs in the more ſwiftly to bring it to an *Æquilibration*, as we ſee Water runs the faſter for having a great declivity.

7. Why in more Northerly places the variations of the Baroſcope *are greater than in the Southerly.* The truth of the Matter of Fact is prov'd from Obſervations made at *Clermont* and *Paris* compar'd with others, made at *Stockholm* as may be ſeen in the Appendix to Mr. Paſcals Book before cited. The Reaſon I conjecture to be that the more Northerly Parts have uſually greater Storms of Wind than the more Southerly, whereby the *Mercury* ſhould ſink lower in that extream; and then the Northerly Winds bringing the condens'd and ponderous *Air* from the Neighbourhood of the Pole, and that again being checked by a Southerly Wind, at no great diſtance, and ſo heaped muſt of neceſſity make the *Mercury* in ſuch caſe ſtand higher, in the other extream.

8. And Laſtly, *Why near the* Æquinoctial *as at* Barbadoes *and St*. Helena, there is very little or no Variation of the height of the Barometer. This Remark, above all others, confirms the Hypotheſis of the variable Winds, being the cauſe of theſe Variations of the height of the *Mercury*; for in the places above-named, there is always an eaſie Gale of Wind blowing nearly upon the ſame Point, *viz.* E, N, E, at *Barbadoes*, and E, S, E, at St. *Helena*; ſo that there being no contrary Currents of the Air, to exhauſt or accumulate it, the Atmoſphere continues much in the ſame State: However upon Hurricanes, the moſt violent of Storms, the *Mercury* has been obſerv'd very low, but this is but for once in two or three Years, and it ſoon recovers its ſettled ſtate of about 29½ Inches. I doubt not but the ſame thing is in the Eaſt Coaſt of *Africa*, and in *India*, where the Monſoons or Winds are Trade for half the Year one way, and half the Year another; only its probable, that there may ſomething worth noting happen, about the times of the change or ſhifting of the Winds, which might be obtain'd

tain'd if any Body had the curioſity to keep the *Barometer* at our Factories in *India.*

I doubt not but this Doctrine will find ſome Oppoſers, and that one principal Objection will be, that I ſuppoſe the *Air* ſometimes to move *from* thoſe parts where it is already evacuated below the *Equilibrium*, and ſometimes again *towards* thoſe parts, where it is condens'd and crouded above the mean ſtate, which may be thought contradictory to the Laws of Staticks and the Rules of the *Equilibrium* of Fluids. But thoſe that ſhall conſider how, when once an impetus is given to a Fluid Body, it is capable of mounting above its level, and checking others that have a contrary tendency to deſcent by their own Gravity, will no longer regard this as a material Obſtacle, but will rather conclude; that the great *Analogy* there is between the riſing and falling of the Water upon the Flux and Reflux of the Sea, and this of the accumulating and extenuating the Air, is a great Argument for the Truth of this Hypotheſis: For as the Sea overagainſt the Coaſt of *Eſſex*, riſes and ſwells by the meeting of the two contrary Tides of Flood, (whereof the one comes from the S. W. along the Channel of *England*, and the other from the North); and on the contrary ſinks below its level upon the retreat of the Water both ways in the Tide of Ebb; ſo it is very probable that the Air may Ebb and Flow, after the ſame manner; but by reaſon of the diverſity of Cauſes, whereby the *Air* may be ſet in moveing, the times of theſe *Fluxes* and *Refluxes* thereof, are purely Caſual and not reducible to any Rule, as are the Motions of the Sea, depending wholly upon the regular Courſe of the Moon.

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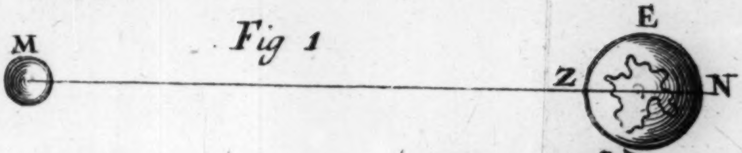
Fig 1

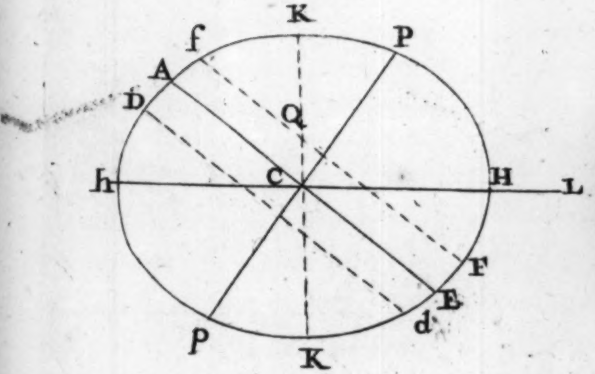
Fig. 2

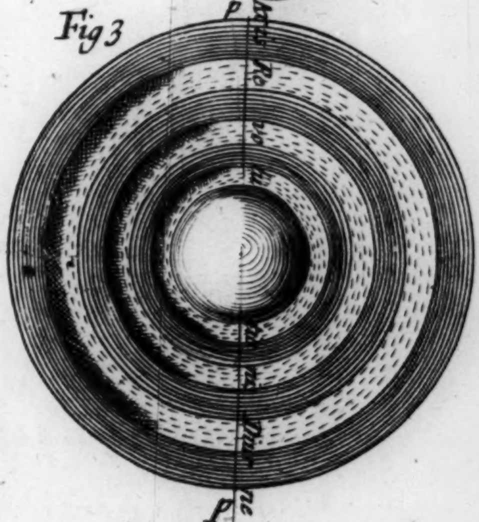
Fig 3

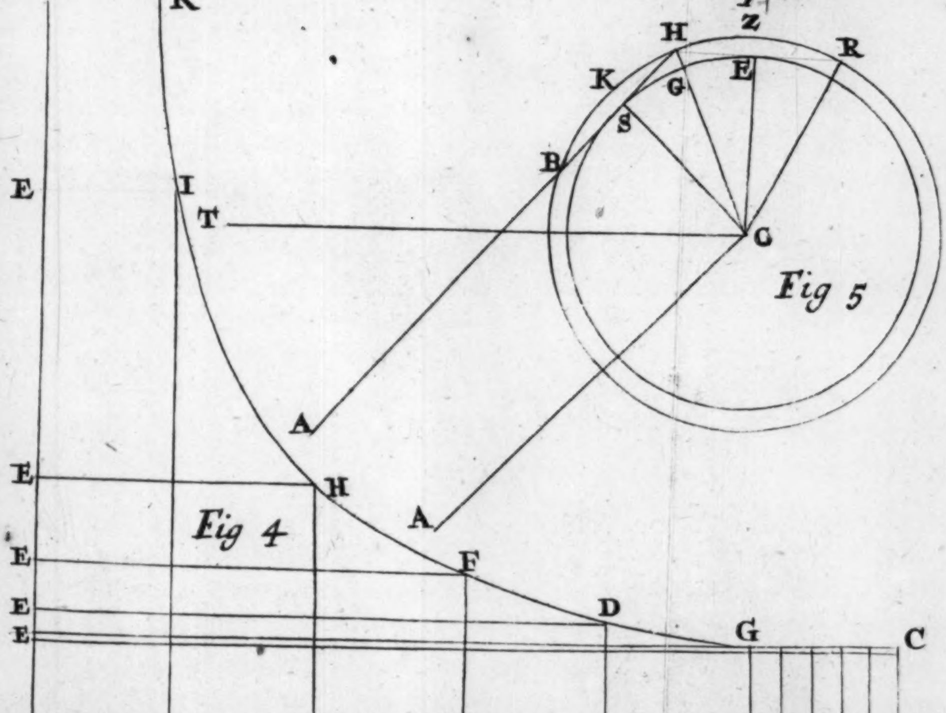
Fig 4

Fig 5

A Letter of Mr. Iſaac Newton, *Profeſſor of the Mathematicks in the Univerſity of* Cambridge; *containing his New Theory about* Light *and* Colours: *Sent by the Author to the Publiſher from* Cambridge, *Febr.* 6. 16$\frac{71}{72}$; *in order to be communicated to the* R. Society.

SIR,

TO perform my late promiſe to you, I ſhall without further Ceremony acquaint you, that in the beginning of the Year 1666 (at which time I apply'd my ſelf to the grinding of Optick-glaſſes of other Figures than *Spherical*,) I procur'd me a Triangular Glaſs-Priſm, to try therewith the celebrated *Phænomena* of *Colours*. And in order thereto having darken'd my Chamber, and made a ſmall hole in my Window-ſhuts, to let in a convenient quantity of the Suns Light, I plac'd my Priſme at his entrance, that it might be thereby refracted to the oppoſite Wall. It was at firſt a very pleaſing divertiſement, to view the vivid and intenſe Colours produced thereby; but after a while applying my ſelf to conſider them more circumſpectly, I became ſurpriſed to ſee them in an *oblong* Form; which, according to the receiv'd Laws of Refraction, I expected ſhould have been *Circular*.

They were terminated at the ſides with ſtreight Lines, but at the ends, the decay of Light was ſo gradual, that it was difficult to determine juſtly, what was their Figure; yet they ſeem'd *Semcircular*.

Comparing the length of this colour'd *Spectrum* with its breadth, I found it about five times greater; a diſproportion ſo extravagant, that it excited me to a more than ordinary Curioſity of examining, from whence it might proceed. I could ſcarce think, that the various thickneſs of the Glaſs, or the termination with ſhadow or darkneſs, could have any Influence on Light to produce ſuch an effect; yet I thought it not amiſs, firſt to examine thoſe Circumſtances, and ſo try'd, what would happen by tranſmitting Light through parts of the Glaſs of divers thickneſſes, or through holes in the Window of divers bigneſſes, or by ſetting the Priſm without ſo, that the light might paſs through it, and be refracted before it was terminated by the hole: But I found none of thoſe Circumſtances material. The faſhion of the Colours was, in all theſe Caſes, the ſame.

Then I ſuſpected, whether by any unevenneſs in the Glaſs, or other contingent Irregularity, theſe Colours might be thus dilated. And to try this, I took another Priſm like the former, and ſo plac'd it, that the light paſſing through them both, might be refracted contrary ways, and ſo by the latter return'd into that Courſe, from which the former had diverted it. For, by this means, I thought the *regular* effects of the firſt Priſm would be deſtroy'd by the ſecond Priſm, but the *irregular* ones more augmented by the multiplicity of Refractions. The event was, that the light, which by the firſt Priſm was diffuſed into an *oblong* Form, was, by the ſecond, reduc'd into an *orbicular* one with as much regularity, as when it did not at all paſs through them. So that whatever was the cauſe of that length, 'twas not any contingent Irregularity.

I then proceeded to examine more critically, what might be effected by the difference of the incidence of Rays coming from divers parts of the Sun; and to that end, meaſur'd the ſeveral Lines and Angles belonging to the Image. Its diſtance from the Hole or Priſm was twenty two Foot; its utmoſt length $13\frac{1}{4}$ Inches; its breadth $2\frac{5}{8}$; the Diameter of the Hole $\frac{1}{4}$ of an Inch; the Angle, with the Rays, tending towards the middle of the Image, made with thoſe Lines, in which they would have proceeded without Refraction, was 44 Deg. 56′. And the Vertical Angle of the Priſm, 63 Deg. 12′. Alſo the Refractions on both ſides the Priſme, that is, of the Incident, and Emergent Rays, were as near, as I could make them, equal, and conſequently about 54 Deg. 4′. And the Rays fell perpendicularly upon the Wall. Now ſubducting the Diameter of the Hole from the length and breadth of the Image, there remains 13 Inches the length, and $2\frac{3}{8}$ the breadth, comprehended by thoſe Rays, which paſſed through the Center of the ſaid Hole, and conſequently the Angle of the Hole, which that breadth ſubtended, was about 31′, anſwerable to the Suns Diameter; but the Angle, which its length ſubtended, was more than five ſuch Diameters, namely two Deg. 49′.

Having made theſe Obſervations, I firſt computed from them the refractive Power of that Glaſs, and found it meaſur'd by the *ratio* of the Sines, twenty to thirty one. And then, by that *ratio*, I computed the Refractions of two Rays flowing from oppoſite parts of the Sun's *diſcus*, ſo as to differ 31′ in their obliquity of Incidence, and found, that the emergent Rays ſhould have comprehended an Angle of about 31′, as they did, before they were incident.

But becauſe this computation was founded on the Hypotheſis of the proportionality of the ſines of Incidence and Refraction, which, tho' by my own Experience I could not imagine to be ſo erroneous as to make that Angle but 31′, which in reality was two Deg. 49′; yet my curioſity caus'd me again to take my Priſm. And having plac'd it at my Window, as before, I obſerv'd, that by turning it a little about its *Axis* to and fro, ſo as to vary its obliquity to the light, more than an Angle of four or five Degrees, the Colours were not thereby ſenſibly tranſlated from their place on the Wall, and conſequently by that variation of Incidence, the quantity of Refraction was not ſenſibly varied. By this Experiment therefore, as well as by the former computation, it was evident, that the difference of the Incidence of Rays, flowing from divers parts of the Sun could not make them, after decuſſation, diverge at a ſenſibly greater Angle, than that at which they before converged; which being, at moſt, but about thirty one or thirty two Minutes, there ſtill remain'd ſome other cauſe to be found out, from whence it could be two Deg. 49′.

Then I began to ſuſpect, whether the Rays, after their Trajection through the Priſm, did not move in curve Lines, and according to their more or leſs Curvity tend to divers parts of the Wall. And it increas'd my ſuſpicion, when I remember'd that I had often ſeen a Tennis-Ball, ſtruck with an oblique Racket, deſcribe ſuch a curve Line. For, a Circular as well as a Progreſſive Motion being communicated to it by that ſtroak, its parts on that ſide, where the Motions conſpire, muſt preſs and beat the contiguous Air more violently than on the other, and there excite a reluctancy and reaction of the Air proportionably greater. And for the ſame reaſon, if the Rays of Light ſhould poſſibly be globular Bodies, and by their oblique Paſſage out of one Medium into another, acquire a circulating Motion, they ought to feel the greater reſiſtence from the ambient Æther, on that ſide, where this Motions conſpire, and thence be continually bowed to the other. But notwithſtanding this plauſible ground of ſuſpicion, when I came to examine it, I could obſerve no ſuch Curvity in them. And beſides (which was enough for my purpoſe) I obſerv'd, that the difference 'twixt the length of the Image, and Diameter of the Hole, through which the light was tranſmitted, was proportionable to their diſtance.

The gradual removal of theſe ſuſpicions, at length led me to the *Experimentum Crucis*, which was this; I took two Boards, and plac'd one of them cloſe behind the Priſm at the Window, ſo that the light might paſs through a ſmall hole, made in it for the purpoſe, and fall on the other Board, which I plac'd at about twelve Feet diſtance, having firſt made a ſmall hole in it alſo, for ſome of that incident Light to paſs through. Then I plac'd another Priſm behind this ſecond Board, ſo that the Light, trajected through both the Boards, might paſs through that alſo, and be again refracted before it arrived at the Wall. This done, I took the firſt Priſm in my Hand, and turn'd it to and fro ſlowly about its *Axis*, ſo much as to make the ſeveral parts of the Image, caſt on the ſecond Board, ſucceſſively paſs through the hole in it, that I might obſerve to what places on the Wall the ſecond Priſm would refract them. And I ſaw by the variation of thoſe places, that the Light, tending to that end of the Image, towards which the Refraction of the firſt Priſm was made, did, in the ſecond Priſm, ſuffer a Refraction conſiderably greater than the Light tending to the other end. And ſo the true cauſe of the length of that Image was detected to be no other, than that *Light* conſiſts of *Rays differently refrangible*, which, without any reſpect to a difference in their incidence, were, according to their degrees of refrangibility, tranſmitted towards divers parts of the Wall.

When I underſtood this I left off my aforeſaid Glaſs Works; for I ſaw, that the perfection of Teleſcopes was hitherto limited, not ſo much for want of Glaſſes truly figured according to the preſcriptions of Optick-Authors (which all Men have hitherto imagin'd), as becauſe that Light itſelf is a *Heterogeneous mixture of differently refrangible Rays.* So that, were a Glaſs ſo exactly figured, ſo as to collect any one ſort of Rays into one Point, it could not collect thoſe alſo into the ſame point, which having the ſame Incidence upon the ſame Medium are apt to ſuffer a different Refraction. Nay, I wonder'd, that ſeeing the difference of Refrangibility was ſo great, as I found it, Teleſcopes ſhould arrive to that perfection they are now at. For, meaſuring the Refractions in one of my Priſmes, I found, that, ſuppoſing the common Sine of Incidence upon one of its plains, was fourty four Parts, the Sine of Refraction of the utmoſt Rays on the red end of the Colours, made out of the Glaſs into the Air, would be ſixty eight parts, and the Sine of Refraction of the the utmoſt Rays on the other end, ſixty nine parts; ſo that the difference is about a twenty fourth or twenty fifth part of the whole Refraction. And conſequently, the Object-glaſs of any Teleſcope cannot collect all the Rays, which come from one point of an Object, ſo as to make them convene at its *focus* in leſs room than in a Circular ſpace, whoſe Diameter is the fiftieth part of the Diameter of its Aperture; which is an irregularity, ſome hundreds of times greater, than a circularly figured *Lens*, of ſo ſmall a ſection as the Object-glaſſes of long Teleſcopes are, would cauſe by the unfitneſs of its Figure, were Light *uniform*.

This made me take *Reflections* into conſideration, and finding them regular, ſo that the Angle of Reflection of all ſorts of Rays was equal to their Angle of Incidence; I underſtood, that by their mediation, Optick Inſtruments might be brought to any degree of Perfection imaginable, provided a *Reflecting* Subſtance could be found, which would poliſh as finely as Glaſs, and *reflect* as much Light as Glaſs *tranſmits*, and the art of communicating to it a *Parabolick* Figure be alſo attain'd. But there ſeem'd very great difficulties, and I have almoſt thought them inſuperable, when I further conſider'd, that every irregularity in a reflecting Superficies makes the Rays ſtray five or ſix times more out of their due courſe, than the like irregularities in a refracting one: So that a much greater curioſity would be here requiſite, than in Figuring Glaſſes for Refraction.

Amidſt theſe Thoughts I was forc'd from *Cambridge* by the Intervening Plague, and it was more than two Years before I proceeded further. But then having thought on a tender way of poliſhing, proper for Metal, whereby, as I imagin'd, the Figure alſo would be corrected to the laſt; I began to try, what might be effected in this kind, and by degrees ſo far perfected an Inſtrument (in the eſſential parts of it like that I ſent to *London*,) by which I could diſcern *Jupiters* four Concomitants, and ſhew'd them divers times to two others of my Acquaintance. I could alſo diſcern the Moon-like Phaſe of *Venus*, but not very diſtinctly, nor without ſome niceneſs in diſpoſing the Inſtrument.

From that time I was interrupted till this laſt Autumn, when I made the other. And as that was ſenſibly better than the firſt (eſpecially for Day-Objects,) ſo I doubt not but they will be ſtill brought to a much greater perfection by their endeavours, who, as you inform me, are taking care about it at *London*.

I have ſometimes thought to make a *Microſcope*, which in like manner ſhould have, inſtead of an Object-glaſs, a reflecting piece of Metal. And this I hope they will alſo take into conſideration: For thoſe Inſtruments ſeem as capable of improvement as *Teleſcopes*, and perhaps more, becauſe but one reflective piece of Metal is requiſite in them, as you may perceive in *Plate* 3. *Fig.* 1. where *A B* repreſenteth the Object Metal, *C D* the Eye-glaſs, *F* their common Focus, and *O* the other Focus of the Metal, in which the Object is placed.

But to return from this digreſſion, I told you, that Light is not ſimilar, or homogeneal, but conſiſts of *difform* Rays, ſome of which are more refrangible than others: So that of thoſe, which are alike incident on the ſame Medium, ſome ſhall be more refracted than others, and that not by any virtue of the Glaſs, or other external Cauſe, but from a prediſpoſition, which every particular Ray hath to ſuffer a particular degree of Refraction.

I ſhall now proceed to acquaint you with another more notable deformity in its Rays, wherein the *Origin of Colours* is unfolded: Concerning which I ſhall lay down the *Doctrine* firſt, ~~and~~ then, for its examination, give you an Inſtance or two of the *Experiments*, as a Specimen of the reſt.

The Doctrine you will find comprehended and illuſtrated in the following Propoſitions.

1. As the Rays of Light differ in degrees of Refrangibility, ſo they alſo differ in their diſpoſition to exhibit this or that particular Colour. Colours are not *Qualifications of Light*, derived from Refractions, or Reflections of natural Bodies (as 'tis generally believed) but *Original* and *connate Properties*, which in divers Rays are divers. Some Rays are diſpoſed to exhibit a red Colour and no other; ſome a yellow and no other, ſome a green and no other, and ſo of the reſt. Nor are there only Rays proper and particular to the more eminent Colours,

lours, but even to all their intermediate Gradations.

2. To the ſame degree of Refrangibility ever belongs the ſame Colour, and to the ſame Colour ever belongs the ſame degree of Refrangibility. The *leaſt Refrangible* Rays are all diſpoſed to exhibit a *Red* Colour, and contrarily thoſe Rays, which are diſpoſed to exhibit a *Red* Colour, are all the leaſt refrangible: So the *moſt Refrangible* Rays are all diſpoſed to exhibit a deep *Violet Colour*, and contrarily thoſe which are apt to exhibit ſuch a Violet Colour, are all the moſt Refrangible. And ſo to all the intermediate Colours in a continued Series belong intermediate degrees of Refrangibility. And this Analogy 'twixt Colours, and Refrangibility, is very preciſe and ſtrict; the Rays always either exactly agreeing in both, or proportionally diſagreeing in both.

3. The Species of Colour, and degree of Refrangibility proper to any particular ſort of Rays, is not mutable by Refraction, nor by Reflection from natural Bodies, nor by any other cauſe, that I could yet obſerve. When any one ſort of Rays hath been well parted from thoſe of other kinds, it hath afterwards obſtinately retained its Colour, notwithſtanding my utmoſt Endeavours to change it. I have refracted it with Priſmes, and reflected it with Bodies, which in Day-light were of other Colours; I have intercepted it with the coloured Film of Air interceding two compreſſed Plates of Glaſs; tranſmitted it through coloured Mediums, and through Mediums irradiated with other ſorts of Rays, and diverſly terminated it; and yet could never produce any new Colour

out of it. It would by contracting and dilating become more brisk, or faint, and by the loſs of many Rays, in ſome caſes very obſcure and dark; but I could never ſee it changed *in ſpecie*.

4 Yet ſeeming Tranſmutations of Colours may 4 be made, where there is any mixture of divers ſorts of Rays. For in ſuch Mixtures, the component Colours appear not, but, by their mutual allaying each other, conſtitute a midling Colour. And therefore, if by Refraction, or any other of the aforeſaid Cauſes, the difform Rays, latent in ſuch a mixture, be ſeparated, there ſhall emerge Colours different from the colour of the Compoſition. Which colours are not new generated, but only made apparent by being parted; for if they be again intirely mix'd and blended together, they will again compoſe that Colour, which they did before ſeparation. And for the ſame reaſon, Tranſmutations made by the convening of divers Colours are not real; for when the difform Rays are again ſevered, they will exhibit the very ſame Colours, which they did before they entered the Compoſition; as you ſee, *Blue* and *Yellow* Powders, when finely mixed, appear to to the naked Eye *Green*, and yet the Colours of the component Corpuſcles are not thereby really tranſmuted, but only blended. For, when viewed with a good Microſcope, they ſtill appear *Blue* and *Yellow* interſperſedly.

5. There are therefore two ſorts of Colours. The one original and ſimple, the other compounded of theſe. The Original or primary Colours are, *Red*, *Yellow*, *Green*, *Blue*, and a *Violet-purple*, together with Orange, Indico, and an indefinite variety of intermediate Gradations.

6. The ſame Colours in *Specie* with theſe primary ones, may be alſo produced by Compoſition: For, a mixture of *Yellow* and *Blue* makes *Green*; of *Red* and *Yellow*, makes *Orange*; of *Orange* and *Yellowiſh green*, makes *Yellow*. And in general, if any two Colours be mixed, which in the Series of thoſe, generated by the Priſme, are not too far diſtant one from another, they by their mutual alloy compound that Colour, which in the ſaid Series appeareth in the midway between them. But thoſe, which are ſituated at too great a diſtance, do not ſo. *Orange* and *Indico* produce not the intermediate Green, nor Scarlet and Green the intermediate Yellow.

7. But the moſt ſurpriſing and wonderful Compoſition was that of *Whiteneſs*. There is no one ſort of Rays which alone can exhibit this. 'Tis ever compounded, and to its Compoſition are requiſite all the aforeſaid primary Colours, mixed in a due proportion. I have often with admiration beheld, that all the Colours of the Priſm being made to converge, and thereby to be again mixed as they were in the light before it was incident upon the Priſm, reproduced light, intirely and perfectly white, and not at all ſenſibly differing from a *direct* Light of the Sun, unleſs when the Glaſſes, I uſed, were not ſufficiently clear; for then they would a little incline it to *their* Colour.

8. Hence therefore it comes to paſs, that *Whiteneſs* is the uſual Colour of *Light*; for, Light is a confuſed aggregate of Rays indued with all ſorts of Colours, as they are promiſcuouſly darted from the various Parts of luminous Bodies. And of ſuch a confuſed aggregate, as I ſaid, is generated Whiteneſs, if there be a

due proportion of the Ingredients; but if any one predominate, the Light muſt incline to that Colour; as it happens in the blue Flame of Brimſtone, the yellow Flame of a Candle, and the various Colours of the fixed Stars.

9. Theſe things conſidered, the *manner*, how Colours are produced by the Priſm, is evident. For, of the Rays, conſtituting the incident Light, ſince thoſe which differ in Colour proportionally differ in Refrangibility, *they* by their unequal Refractions muſt be ſevered and diſperſed into an oblong Form, in an orderly ſucceſſion from the leaſt refracted Scarlet to the moſt refracted Violet. And for the ſame reaſon it is, that Objects, when looked upon through a Priſm, appear coloured. For, the difform Rays, by their unequal Refractions, are made to diverge towards ſeveral Parts of the *Retina*, and there expreſs the Images of things coloured, as in the former caſe they did the Sun's Image upon a Wall. And by this inequality of Refractions, they become not only coloured, but alſo very confuſed and indiſtinct.

10. Why the Colours of the *Rainbow* appear in falling drops of Rain, is alſo from hence evident. For, thoſe drops, which refract the Rays, diſpoſed to appear purple, in greateſt quantity to the Spectators Eye, refract the Rays of other ſorts ſo much leſs, as to make them paſs beſide it; and ſuch are the drops on the inſide of the *Primary* Bow, and on the outſide of the *Secondary* or Exteriour one. So thoſe drops, which refract in greateſt plenty the Rays, apt to appear red, toward the Spectator's Eye, refract thoſe of other ſorts ſo much more, as to make them paſs beſide it; and ſuch are the

drops on the exteriour part of the *Primary*, and interiour part of the *Secondary* Bow.

11. The odd Phænomena of an infuſion of *Lignum Nephriticum*, *Leaf-gold*, *Fragments of coloured Glaſs*, and ſome other tranſparently coloured Bodies, appearing in one Poſition of one Colour, and of another in another, are on theſe grounds no longer Riddles. For, thoſe are Subſtances apt to reflect one ſort of Light, and tranſmit another; as may be ſeen in a dark room, by illuminating them with ſimilar or uncompounded Light. For, then they appear of that Colour only, with which they are illuminated; but yet in one Poſition more vivid and luminous than in another, accordingly as they are diſpoſed more or leſs to reflect or tranſmit the incident Colour.

12. From hence alſo is manifeſt the reaſon of an unexpected Experiment, which Mr. *Hook* ſomewhere in his *Micrography* relates to have made with two wedge-like tranſparent Veſſels, fill'd the one with a red, the other with a blue Liquor; namely, that though they were ſeverally tranſparent enough, yet both together became opake: For, if one tranſmitted only red, and the other only blue, no Rays could paſs through both.

13. I might add more Inſtances of this Nature; but I ſhall conclude with this general one, that the Colours of all natural Bodies have no other Origin than this, that they are variouſly qualified to reflect one ſort of Light in greater plenty than another. And this I have experimented in a dark room, by illuminating thoſe Bodies with uncompounded Light of divers Colours. For by that means any body may be made to appear of any Colour. They have

there no appropriate Colour, but ever appear of the Colour of the Light caſt upon them; but yet with this difference, that they are moſt briſk and vivid in the Light of their own day-light-colour. *Minium* appeareth there of any Colour indifferently, with which 'tis illuſtrated, but yet moſt luminous in red; and ſo *Biſe* appeareth indifferently of any Colour with which 'tis illuſtrated, but yet moſt luminous in blue. And therefore *Minium* reflecteth Rays of any Colour, but moſt copiouſly thoſe endued with red; and conſequently when illuſtrated with day-light, that is, with all ſorts of Rays promiſcuouſly blended, thoſe qualified with red ſhall abound moſt in the reflected Light, and by their prevalence cauſe it to appear of that Colour. And for the ſame reaſon *Biſe*, reflecting blue moſt copiouſly, ſhall appear blue by the exceſs of thoſe Rays in its reflected Light; and the like of other Bodies. And that this is the intire and adequate cauſe of their Colours, is manifeſt, becauſe they have no power to change or alter the Colours of any ſort of Rays incident apart, but put on all Colours indifferently, with which they are inlightned.

Theſe things being ſo, it can be no longer diſputed, whether there be Colours in the dark, nor whether they be the Qualities of the Objects we ſee, no nor perhaps, whether Light be a Body. For, ſince Colours are the *Qualities* of Light, having its Rays for their intire and immediate Subject, how can we think thoſe Rays *Qualities* alſo, unleſs one Quality may be the ſubject of and ſuſtain another; which in effect is to call it *Subſtance*. We ſhould not know Bodies for Subſtances, were it not for their ſenſible Qualities; and the principal of thoſe being now found due to ſomething elſe, we have as good reaſon to believe that to be a Subſtance alſo.

Beſides, whoever thought any Quality to be a *heterogeneous* aggregate, ſuch as Light is diſcovered to be? But, to determine more abſolutely, what Light is, after what manner refracted, and by what modes or actions it produceth in our Minds the Phantaſms of Colours, is not ſo eaſie. And I ſhall not mingle Conjectures with Certainties.

Reviewing what I have written, I ſee the Diſcourſe it ſelf will lead to divers Experiments ſufficient for its Examination; and therefore I ſhall not trouble you farther, than to deſcribe one of thoſe, which I have already inſinuated.

In a darkened Room, make a hole in the ſhut of a Window, whoſe Diameter may conveniently be about a third part of an Inch, to admit a convenient quantity of the Sun's Light: And there place a clear and colourleſs Priſm, to refract the entring Light towards the farther part of the room; which, as I ſaid, will thereby be diffuſed into an oblong coloured Image. Then place a *Lens* of about three Foot Radius (ſuppoſe a broad Object-glaſs of a three Foot Teleſcope,) at the diſtance of about four or five Foot from thence, through which all thoſe Colours may at once be tranſmitted, and made by its Refraction to convene at a farther diſtance of about ten or twelve Feet. If at that diſtance you intercept this Light with a ſheet of white Paper, you will ſee the Colours converted into whiteneſs again by being mingled. But it is requiſite, that the *Priſm* and *Lens* be placed ſteddy, and that the Paper, on which the Colours are caſt, be moved to and fro; for, by ſuch motion, you will not only find at what diſtance the whiteneſs is moſt perfect, but alſo ſee, how the Colours gradually convene, and vaniſh into whiteneſs ; and afterwards, having croſſed one another in that place where they compound Whiteneſs, are again diſſipated and ſevered, and in an inverted order retain the ſame Colours, which they had before they entered the Compoſition. You may alſo ſee, that, if any of the Colours at the *Lens* be intercepted, the Whiteneſs will be changed into the other Colours. And therefore, that the Compoſition of whiteneſs be perfect, care muſt be taken that none of the Colours fall beſides the *Lens*.

In the annexed Deſign, *Tab*. 3. *Fig*. 2. of this Experiment, *ABC* expreſſeth the Priſm ſet endwiſe to ſight, cloſe by the hole *F* of the Window *EG*. Its vertical Angle *ABC* may conveniently be about 60 degrees: *MN* deſigneth the *Lens*. Its breadth 2½ or 3 Inches. *SF* one of the ſtreight Lines, in which difform Rays may be conceived to flow ſucceſſively from the Sun. *FP*, and *FR* two of thoſe Rays unequally refracted, which the *Lens* makes to converge towards Q, and after decuſſation to diverge again. And HI the Paper, at divers diſtances, on which the Colours are projected which in *Q* conſtitute *Whiteneſs*, but are *Red* and *Yellow* in *R*, *r*, and *ρ*, and *Blue* and *Purple* in *P*, *p*, and *π*.

If you proceed further to try the impoſſibility of changing any uncompounded Colour (which I have aſſerted in the third and thirteenth Propoſitions,) 'tis requiſite that the Room may be very dark, leſt any ſcattering light, mixing with the Colour, diſturb and allay it, and render it compound, contrary to the deſign of the Experiment. 'Tis alſo requiſite, that there be a perfecter ſeparation of the Colours, than, after the manner above deſcribed, can be made by the Refraction of one ſingle Priſm; and how to make ſuch farther ſeparations, will ſcarce be difficult to them, that conſider the diſcovered Laws of Refractions. But if trial ſhall be made with Colours not througly ſeparated, there muſt be allowed changes proportionable to the mixture. Thus if compound Yellow light fall upon blue *Biſe*, the Biſe will not appear perfectly yellow, but rather green, becauſe there are in the yellow mixture many Rays indued with green, and green being leſs remote from the uſual blue Colour of Biſe than yellow, is the more copiouſly reflected by it.

In like manner, if any one of the Priſmatick Colours, ſuppoſe red, be intercepted, on deſign to try the aſſerted impoſſibility of reproducing that Colour out of the others which are pretermitted; 'tis neceſſary, either that the Colours be very well parted before the red be intercepted; or that, together with the red, the neighbouring Colours, into which any red is ſecretly diſperſed, (that is, the yellow, and perhaps green too) be intercepted; or elſe, that allowance be made for the emerging of ſo much red out of the yellow green, as may poſſibly have been diffuſed, and ſcatteringly blended in thoſe Colours. And if theſe things be obſerved, the new Production of red, or any intercepted Colour will be found Impoſſible.

This, I conceive, is enough for an Introduction to Experiments of this kind; which if any of the *Royal Society* ſhall be ſo curious as to proſecute, I ſhould be very glad to be informed with what ſucceſs: That, if any thing ſeem to be defective, or to thwart this Relation, I may have an opportunity of giving farther Direction about it, or of acknowledging my Errors, if I have committed any.

Since the Publication of this Theory, ſome Miſunderſtandings happening between a French *Philoſopher at* Paris *and Mr.* Newton, *he has endeavour'd to explain himſelf a little further in theſe Things according to the following Method.*

DEFINITIONS.

1. I call that Light Homogeneal, Similar, or Uniform whoſe Rays are equally refrangible.

2. And that Heterogeneal, whoſe Rays are unequally refrangible.

Note, There are but three Affections of Light in which I have obſerved its Rays to differ; *viz.* Refrangibility, Reflexibility, and Colour; and thoſe Rays which agree in Refrangibility agree alſo in the other two, and therefore may well be defined Homogeneal; eſpecially ſince Men uſually call thoſe things Homogeneal, which are ſo in all Qualities that come under their Knowledge, 'though in other Qualities that their Knowledge extends not to, there may poſſibly by ſome Heterogeneity.

3. Thoſe Colours I call Simple or Homogeneal, which are exhibited by Homogeneal Light.

4. And thoſe Compound or Heterogeneal, which are exhibited by Heterogeneal Light.

5. Different Colours, I call, not only the more eminent Species Red, Yellow, Green, Blue, Purple, but all other the minuteſt Gradations;

much after the ſame manner, that not only the more eminent Degrees in Muſick, but all the leaſt Gradations, are eſteemed different Sounds.

PROPOSITIONS.

1. The Sun's Light conſiſts of Rays differing by indefinite Degrees of Refrangibility.

2. Rays which differ in Refrangibility, when parted from one another, do proportionally differ in the Colours which they exhibit. Theſe Two Propoſitions are Matter of Fact.

3. There are as many Simple or Homogeneal Colours, as Degrees of Refrangibility. For to every Degree of Refrangibility belongs a different Colour, by *Prop.* 2. and that Colour is ſimple, by *Def.* 1. and 3.

4. Whiteneſs, in all reſpects like that of the Sun's immediate Light, and of all the uſual Objects of our Senſes, cannot be compounded of two ſimple Colours alone. For ſuch a Compoſition muſt be made by Rays that have only two Degrees of Refrangibility, by *Def.* 1, and 3. and therefore it cannot be like that of the Sun's Light, by *Prop.* 1. nor, for the ſame Reaſon, like that of ordinary white Objects.

5. Whiteneſs, in all reſpects, like that of the Sun's immediate Light, cannot be compounded of ſimple Colours without an indefinite Variety of them. For to ſuch a Compoſition, there are requiſite Rays endued with all the indefinite Degrees of Refrangibility, by *Prop.* 1. And thoſe infer as many ſimple Colours, by *Def.* 1, and 3. and *Prop.* 2, and 3.

To make theſe a little plainer, I have added alſo the Propoſitions that follow.

6. The Rays of Light do not act on one another, in paſſing thro' the ſame Medium.

7. The Rays of Light ſuffer not any change of their Qualities from Refraction.

8. Nor afterwards from the adjacent quiet *Medium*: Theſe two Propoſitions are manifeſt *de Facto* in Homogeneal Light, whoſe Colour and Refrangibility is not at all changeable, either by Refraction, or by the contermination of a quiet *Medium*. And as for Heterogeneal Light, it is but an Aggregate of ſeveral ſorts of Homogeneal Light, no one ſort of which ſuffers any more alteration than if it were alone; becauſe the Rays act not on one another, by *Prop.* 6. and therefore the Aggregate can ſuffer none. Theſe two Propoſitions alſo might be further proved apart, by Experiments too long to be here deſcribed.

9. There can no Homogeneal Colours be educed out of Light by Refraction, which were not commixt in it before: Becauſe by *Prop.* 7, and 8. Refraction changeth not the Qualities of the Rays, but only ſeparates thoſe which have divers Qualities, by means of their different Refrangibility.

10. The Sun's Light is an Aggregate of an indefinite Variety of Homogeneal Colours, by *Prop*, 1, 3, and 9. And hence it is, that I call Homogeneal Colours alſo Primitive or Original. And thus much concerning Colours.

For a further Illuſtration of this Doctrin, Mr. Newton, *in his Book of Opticks lately publiſhed, has by undeniable Experiments explained moſt of the Principal Phænomena of Light and Colours: To which we refer the Reader.*

A Demonſtration concerning the Motion of Light, communicated from Paris.

PHiloſophers have been labouring for many Years to decide by ſome Experiment, whether the Action of Light be conveyed in an inſtant to diſtant Places, or whether it requireth time. M. *Romer*, of the *Royal Academy* of Sciences, hath deviſed a way taken from the Obſervations of the firſt Satellit of *Jupiter*, by which he demonſtrates, that for the diſtance of about 3000 Leagues, ſuch as is very near the bigneſs of the Diameter of the Earth, Light needs not one Second of Time.

Let (in *Fig.* 3. *Plate* 3.) *A* be the *Sun*, *B Jupiter*, *C* the firſt Satellit of *Jupiter*, which enters into the ſhadow of *Jupiter*, to come out at *D*, and let *E F G H K L* be the *Earth*, placed at divers diſtances from *Jupiter*.

Now ſuppoſe the *Earth*, being in *L* towards the ſecond Quadrature of *Jupiter*, hath ſeen the firſt Satellit, at the time of its emerſion, or iſſuing out of the ſhadow at *D*, and that about 42½ hours after (*viz.* after one Revolution of this *Satellit*) the *Earth* being in *K*, do ſee it returned in *D*: It is manifeſt, that if the Light require time to traverſe the Interval *L K*, the *Satellit* will be ſeen returned later in *D*, than it would have been if the *Earth* had remained in *L*. So that the Revolution of the *Satellit* being thus obſerved by the Emerſions, will be retarded by ſo much time, as the Light ſhall have taken in paſſing from *L* to *K*; and that on the contrary, in the other Quadrature *FG*, where the *Earth* by approaching goes to meet the Light, the Revolutions of the Emerſions will appear to be ſhortned, by ſo much as thoſe of the Emerſions had appear'd to be lengthned. And becauſe 42½ hours, which this *Satellit* very near takes to make one Revolution, the diſtance between the *Earth* and *Jupiter*, in both the Quadratures, varies at leaſt 210 Diameters of the *Earth*: It follows, that if for the Account of every Diameter of the *Earth* there were required a Second of Time, the Light would take 3½ Minutes for each of the Intervals *G F*, *K L*; which would cauſe near half a quarter of an Hour between two Revolutions of the firſt *Satellit*, one obſerved in *F G*, and the other in *K L*, whereas there is not obſerved any ſenſible difference.

Yet doth it not follow hence, that Light demands no time. For after M. *Romer* had examin'd the thing more nearly, he found that what was not ſenſible in two Revolutions, became very conſiderable in many being taken together; and that, for Example, forty Revolutions obſerved on the ſide *F*, might be ſenſibly ſhorter, than forty others obſerved in any place of the *Zodiack* where *Jupiter* may be met with; and that in proportion of Twenty two for the whole Interval of *H E*, which is the double of the Interval that is from hence to the Sun.

The Neceſſity of this new Equation of the retardment of Light, is eſtabliſhed by all the Obſervations that have been made in the *Royal Academy*, and in the *Obſervatory*, for the ſpace of eight Years; and it hath been lately confirmed by the Emerſion of the firſt *Satellit* obſerved at *Paris*, the 9th of *Novembor* laſt, at 5 a-clock 35′ 45″ at night, 10 minutes later than it was to be expected, by deducting it from thoſe that had been obſerved in the Month of *Auguſt*, when the *Earth* was much nearer to *Jupiter*; which M. *Romer* had predicted to the ſaid Academy from the beginning of *September*.

But to remove all doubt, that this Inequality is cauſed by the retardment of the Light, he demonſtrates, that It cannot come from any Excentricity or other cauſe of thoſe that are commonly alledged to explicate the Irregularities of the *Moon*, and the other Planets; tho' he be well aware, that the firſt *Satellit* of *Jupiter* was excentrick; and that, beſides his Revolutions were advanced or retarded, according as *Jupiter* did approach to or recede from the Sun; as alſo, that the Revolutions of the *Primum Mobile* were unequal: Yet, ſaith he, theſe three laſt cauſes of Inequality do not hinder the firſt from being manifeſt.

An introductory Eſſay *to the Doctrine of* Sounds, *containing ſome Propoſals for the improvement of* Acouſticks; *As it was preſented to the* Dublin Society, *Nov.* 12. 1683, *by the Right Reverend Father in God* Narciſſus *Lord Biſhop of* Ferns *and* Leighlin.

BEing to treat of the Doctrine of *Sounds*, I hold it convenient to premiſe ſomething in the general concerning this Theory; which may ſerve at once to ingage your Attention, and excuſe my pains, when I ſhall have recommended them, as beſtow'd on a Subject not altogether uſeleſs and unfruitful.

And for this purpoſe I ſhall omit to ſpeak any thing of the *Excellency* of the Matter in Hand; tho' it might be celebrated by Arguments drawn from ſeveral Topicks, and particularly from this, that new Diſcoveries and Improvements may be made both as to the *Generation*, *Propagation* and *Reception* of Sounds into the Senſe; which, in a peculiar manner agrees to this, above the Object of any other Senſe whatſoever. I ſhall, I ſay, omit theſe things, and apply my ſelf wholly to the *Uſefulneſs* of the Theory, that we are now falling upon; which I think cannot better be diſcovered, than by making a compariſon 'twixt the

Senſes of *Seeing* and *Hearing* as to their Improvements. I mean, by ſhewing, that this latter of *Hearing* is capable of all thoſe improvements which the Senſe of *Seeing* has receiv'd from Art, beſides many more advantages that the *Ear* may enjoy, by the help of our Doctrine, above the *Eye*; all which moreover will be of as great benefit to Mankind, as any thing that *Opticks* have yet diſcover'd, if not of greater; which, with ſome other preeminencies that it has upon another Score, will happily render *Acouſticks* the nobler Science of the two.

In order to the making good what I but now promiſed of the Compariſon of theſe two Faculties of *Seeing* and *Hearing*, as to their Improvements, I obſerve,

That *Viſion* is threefold, *Direct*, *Refracted*, and *Reflex'd*; anſwerable whereunto we have *Optick*, *Diopttricks*, and *Catoptricks*.

In like manner *Hearing* may be divided into *Direct*, *Refracted* and *Reflex'd*; whereto anſwer three parts of our Doctrine of *Acouſticks*, which are yet nameleſs, unleſs we call them *Acouſticks*, *Diacouſticks*. and *Cathacouſticks*, or (in another Senſe, but to as good Purpoſe) *Phonicks*, *Diaphonicks*, and *Cataphonicks*.

1. Direct Viſion has been improv'd two ways, *ex parte* Objecti, and *ex parte* Organi *vel* Medii.

1. *Ex parte Objecti* Direct Viſion has receiv'd advantages by the Arts of *Producing*, *Conſerving* and *Imitating Light* and *Colours*, which are the Objects of Viſion.

1. For the Art of *Producing Light*, we have the Frication of all hard Bodies that beget Fire; eſpecially of the Flint and Steel; and

inſtead of the Flint, moſt hard Stones (as well as the Cane) may be us'd to the ſame effect, as upon trial I have found. Add hereto the lately invented *Phoſphorus*, which is a new and admirable way of producing a *Lucid Subſtance* by Art, out of a Body in itſelf not *Lucid*; and therefore may not unfitly be term'd an *Artificial production* of *Light.*

And then of the Art of *Concerving Light*, the *Lapis Bononienſis* is a notable inſtance; and ſo happily were the *Sepulchral Lamps* of the Ancients.

2. As to *Colours*, 'tis the greateſt part of the Art of *Dying* to be able to make and fix (that is preſerve) them; and the *Painters* and *Limners* will own it to be no ſmall part of their Skill to be able well to *Mix* (that is, in effect, to *Generate*) *Colours.*

3. For *Imitation of Light* and *Colours*, 'tis well known how far *Perſpective* with the Art of *Limning* and *Shadowing* have gone therein, which all tend ſome way to the Advance or Improvement of *Direct Viſion.*

Add to all theſe, That *a due Application of Light to the Object* renders it Viſible, if it were not ſo before; as appears from a dark Room illuminated; or elſe makes it better and more truly diſcernable by the Senſe of *Seeing*, if before it might have been diſcern'd.

Hence the ſame *Colour*, in a divers Light, will appear different, and no *Picture* can well be diſcern'd or judg'd of but by its true Light. Beſides, the *Limner* will aſſure you, that he can hardly make true Work or hit the Air of a Face exactly, unleſs we draw by a *North-Light*, by reaſon of the Steddineſs of that, and the uncertainty of all other Lights whatſoever.

Which things ſhew, that the *Art of duly applying Light to the Object* does very much help and improve Viſion. So alſo does the due placing of the *Object*, as to *Height* and *Diſtance.* But to enumerate all things that help *Direct Viſion*, would be infinite.

2. *Ex parte Organi vel Medii* Direct Viſion has been improv'd by making uſe of a *Tube*, without Glaſſes, or a Man's clos'd Hand, to look thro'; which admitting into the *Eye* only the principal Rays, that come directly from the Object, do very much ſtrengthen and clear the Sight, by excluding all the Collateral Rays, that crouding into the Eye, together with the direct ones, would confound and diſturb it, partly by mixing and interfering with the Direct Rays, and partly (or rather chiefly) by too much enlightning the fund of the Eye, wherein Viſion is truly (tho' then imperfectly) made.

On this is founded the Art of making *Spectacles* without Glaſſes; (as well as *Tubes*) which is done by putting into the Glaſs-holes (inſtead of Glaſſes) two ſhort *Tubes* of between three and four Inches long (for their length is to be vary'd according to the Age or Eye of the beholder, and ſo alſo is the Diameter of the extream ends) which *Tubes* being made of *Spaniſh Leather* (or Paſt-board, or ſome ſuch like matter) and black'd on the inſide, are ſo to be plac'd, as that the viſual Rays, receiv'd thro' them, may meet in one Point (or rather iſſue out from one Point) of the Object ſtanding at ſuch a due diſtance, as the Perſon may clearly and diſtinctly ſee it, or according to his length of Sight (as ABC, in the 4th Fig. *Tab.* 3.)

And theſe *Spectacles* may be ſuppos'd better for preſerving the Sight, than the ordinary ones with Glaſſes, becauſe they repreſent the Object more naturally, and withal more clearly and diſtinctly to the Eye, than the other, whoſe refracted Rays being collected together with the right ones in the Glaſſes, do ſomewhat confound good Viſion, (as before): Eſpecially if the viſive Power be ſtrong enough to be ſufficiently determin'd by the right Rays alone.

For I ſpeak now of preſerving a good Eye by theſe Spectacles, which holds in proportion true alſo of a bad one. Becauſe thoſe Rays (both right and refracted) being collected and brought ſo near the Eye (whether good or bad) as the Spectacles are uſually plac'd, do too much affect it, both by their own brightneſs, and alſo by the brightneſs of the Colours of the Object (when they are bright) which is brought very near alſo; whereby the Eye is dazl'd and confounded, unleſs there be a ſtrong attention and *conatus* of the Spirits, whereto the bright Rays do certainly engage them, which of neceſſity weakens Viſion, eſpecially if theſe Glaſs-ſpectacles be much us'd.

Wherefore the now deſcrib'd new Tube-ſpectacles, contributing ſo much to the help and preſervation of Sight, may well be counted an improvement of *Direct Viſion*, becauſe they convey the Rays to the Eye without any kind of refraction whatſoever. Seeing the ſame Object alſo through various holes, plac'd at certain diſtances, does ſomewhat alter Viſion; but of this perhaps more hereafter.

Now as *Direct Viſion* has thus been improved, ſo likewiſe *Direct Hearing* partly has already receiv'd, and partly may (by the Doctrine whereof we are treating, (if well cultivated) farther receive as great and notable Improvements, both *ex parte* Objecti, and *ex parte* Organi *vel* Medii.

1. As to the *Object* of Hearing, which is Sound, improvement has been and may be made, both as to the *Begetting*, and as to the *Conveying* and *Propagating* (which is a kind of *Conſerving*) of Sounds.

1. As to the *Begetting* of Sounds. The Art of imitating any Sound, whether by *Speaking* (that is pronouncing) ~~any~~ any kind of Language, (which really is an Art, and the *Art of ſpeaking* perhaps one of the greateſt) or by *Whiſtling*, or by *Singing* (which are allow'd Arts) or by *Hollowing* or *Luring* (which the Huntſman or Faulkner would have to be an Art alſo) or by imitating with the Mouth (or otherwiſe) the Voice of any Animal, as of *Quails*, *Cats*, and the like, or by *Repreſenting* any Sound begotten by the Colliſion of Solid Bodies, or after any other manner; theſe are all *Improvements* of *Direct Hearing*, and may be improv'd.

Moreover the Skill to make all ſorts of *Muſical Inſtruments*, both Ancient and Modern, whether *Wind* Inſtruments or *String'd*, or of any other ſort, whereof there are very many (as *Drums*, *Bells*, the *Syſtrum* of the *Egyptians*, and the like) that beget (and not only propagate) Sounds; the Skill of making theſe, I ſay, is an Art, that has as much improv'd *Direct Hearing*, as an Harmonious Sound exceeds a ſingle and rude one, that is, an immuſical *Tone*; which Art is yet capable of farther improvement. And I do hope, that by the Rules, which may happily be laid down concerning the *Nature*, *Propagation* and *Proportion* or *A-*

dapting of Sounds, a way may be found out, both to improve *Muſical Inſtrumeuts* already in uſe, and to invent new ones, that ſhall be more ſweet and luſhious, than any yet known. Beſides that, by the ſame means *Inſtruments* may be made, that ſhall imitate any ſound in Nature, that is not Articulate, be it of Bird, Beaſt, or what thing elſe ſoever.

2. The *Conveying* and *Propagating* (which is a kind of *Conſerving*) of Sounds, is much help'd by *duly placing the Sonorous Body*, and alſo by the *Medium.*

For if the Medium be *Thin* and *Quieſcent*, and the Sounding Body *plac'd conveniently*, the Sound will be eaſily and regularly propagated, and mightily conſerv'd. I ſay,

1. If the *Medium be thin and Quieſcent*, becauſe it otherwiſe cauſes a *Refracted Sound*, of which afterwards. Hence in a *ſtill Evening* or the *dead of the Night* (when the Wind ceaſes) a Sound is better ſent out and to a greater diſtance than otherwiſe, tho' much of this may be aſcrib'd to it's *Refraction* alſo.

2. I ſay, that the *Sonorous Body muſt be plac'd conveniently*, near a *Smooth Wall*, near *Water*, or *a Plain*, whoſe Surface is even.

1. Near *a Smooth Wall*, either Plain or Arch'd (Cycloidically or Elliptically, rather than otherwiſe, tho' a Circular or any Arch will do, but not ſo well.)

Hence in a Church, the nearer the Preacher ſtands to the Wall (and certainly 'tis much the beſt way to place Pulpits near the Wall) the better is he heard, eſpecially by thoſe who ſtand near the Wall alſo, though at a greater diſtance from the Pulpit; thoſe at the remoteſt end of the Church, by laying their Ears ſomewhat

what cloſe to the Wall, may hear him eaſier than thoſe in the middle.

Hence alſo do ariſe *Whiſpering Places.* For the Voice being apply'd to one end of an Arch, eaſily rowls to the other. And indeed were the *motion* and *propagation* of Sounds but rightly underſtood, 'twould be no hard matter to contrive *Whiſpering Places* of infinite variety and uſe. And perhaps there could be no better or more pleaſant hearing a *Conſort of Muſick* than at ſuch a place as this, where the Sounds rowling along together, before they come to the Ear, muſt needs conſolidate and imbody into one; which becomes a true compoſition of Sounds, and is the very Life and Soul of Conſort.

2. If the Sonorous Body be plac'd near *Water* the Sound will eaſily be convey'd, yet mollified; as Experience teacheth us from a Ring of *Bells* near a River and a great *Gun* ſhot off at Sea, which differ much in the ſtrength, and yet ſoftneſs and continuance or propagation of their Sounds, from the ſame at Land, where the Sound is more harſh and more periſhng, or much ſooner decays.

3. In a *Plain* a Voice may be heard at a far greater diſtance than in uneven Ground.

The *Reaſon* of all which laſt nam'd *Phænomena* is the ſame, becauſe the Sonorous Air meetting with little or no reſiſtence upon a *Plane* (much leſs upon an Arch'd) ſmooth Superficies eaſily rowls along it, without being let or hindred in its Motion, and conſequently without having its parts diſfigured, and put into another kind of Revolution, than what they had at the firſt begetting of the Sound. Which is the true cauſe of its *Preſervation* or *Progreſſion*, and fails much when the Air paſſes over an uneven

even Surface, according to the degrees of its inequality, and ſomewhat alſo, when it paſſes over the plain Superficies of a Body that is hard and reſiſting.

Wherefore the ſmooth top of the Water (by reaſon of its yielding to the Arch'd Air, and gently riſing again with a kind of reſurge, like to *Elaſticity*, tho' it be not ſo, by which reſurge it quickens and haſtens the motion of the Air rowling over it, and by its yielding preſerves it in its Arch'd Cycloidical or Eliptical Figure) the ſmooth top of the Water, I ſay, for theſe reaſons, and by theſe means, conveys a Sound more entire and to a greater diſtance than the plain Surface of a piece of Ground, a Wall, or any other Solid Body whatever can do.

As for the *Speaking Trumpet*, by which a Voice may be convey'd to a conſiderable diſtance, I refer its conſideration to that of *Refracted Sounds* or *Refracted Audition.*

Thus much of the Improvements of Hearing, that reſpect its *Object* which is *Sound.*

2. The *Organ* and *Medium* are to be conſidered. And, 1. The *Organ*, which is the *Ear*, is helpt much by placing it near a Wall (eſpecially at one end of an Arch, the Sound being begotten at the other) or near the Surface of Water, or of the Earth, along which the Sounds are moſt eaſily and naturally convey'd, as was before declar'd. And 'tis incredible how far a Sound made upon the Earth (by the trampling of a Troop of Horſes, for Example) may be heard in a ſtill Night, if a Man lays his Eear cloſe to the Ground in a large Plain.

Otacouſticks here come in for helping the *Ear*; which may be ſo contriv'd (by a right underſtanding the *Progreſſion of Sounds*, which is the principal thing to be known for the due regulating all ſuch kinds of Inſtruments) as that the Sound might enter the Ear without any Refraction, but as now they are generally made I refer them to *Refracted Audition*.

2. As to the *Medium*, I know not how that, by any contrivance of Art, can advantage *Direct Hearing*, otherwiſe than I have declar'd already in the propagation or conveiance of Sounds, tho' to the Refacting or Reflecting of them it may very much conduce; of which preſently.

And ſo I have done with the firſt part of my preſent undertaking, which is the *Compariſon of Direct Viſion and Audition*, as to their Improvements from Art. The reſt follow. Wherefore,

II. Concerning *Refracted Viſion* and its Compariſon, I obſerve, That *Refracted Viſion* is always made *Ex parte Medii*, as *Reflected* is *ex parte Objecti*. And therefore tho' *Direct Viſion* may be help'd *ex parte Objecti*, *Medii vel Organi*; yet *Refracted* can be improv'd only *ex parte Medii*, and *Reflected ex parte Corporis oppoſiti* alone. Unleſs it be in a mixt or compound Viſion, that is *Refracto-Reflext*, when the reflext Rays paſs to the Eye through a refracting Medium, ſuch as the Medium Internum, contain'd in the Body of the Eye always is. So that in truth all Viſion is *Refracted* by an internal Refraction made in *ipſo Oculo*.

And all that I have ſpoken of *Viſion* holds true of *Hearing* alſo, both *Refracted* and *Reflext*, and therefore need not be repeated.

Refracted Viſion ariſes from the different *Denſity*, *Figure* and *Magnitude* of the Medium, which is ſomewhat alter'd alſo by the divers incidence of the viſible Rays. And ſo it is in *Refracted Hearing*, all theſe Cauſes concur to its Production, and ſome others to be hereafter conſider'd.

Now as any Object (a Man for example) ſeen through a thicken'd Air, by *Refraction* appears greater than really he is: So likewiſe a *Sound*, heard through the ſame thickned part of the *Atmoſphere*, will be conſiderably vary'd from what it would ſeem to be, if heard through a thinner Medium.

And this I call a *Refracted Sound*: But what this Refraction of Sound is, and how caus'd, may hereafter be diſcuſs'd, when the Nature, and Motion, or Progreſſion of Sounds are well ſtated.

For the Improvement of *Refracted Viſion* artificial Inſtruments have been made, by grinding or blowing Glaſſes into a certain Figure, and placing them at due diſtances, whereby the Object may be (as 'twere) enabled to ſend forth its Rays more vigorouſly, and the Viſive Faculty impower'd the better to receive them. And thus alſo Inſtrumnents may be contriv'd for the aſſiſting both the *Sonorous Body*, to ſend forth its Sound more ſtrongly, and the *Acouſtick Faculty* to receive and diſcern it more eaſily and clearly. *For*,

1. As a fine *Glaſs Bubble*, fill'd with clear Water, and plac'd before a burning Candle or Lamp, does help it to dart forth its Rays to a §

prodigious

prodigious length and brightneſs: So an *Inſtrument* may be invented, that apply'd to the Mouth (or any Sonorous Body) ſhall ſend forth the Voice diſtinctly to as prodigious a diſtance and loudneſs.

For if the *Stentoro-phonecon* (which is but a rude and unartificial Inſtrument) does ſuch great feats, what might be done with one compos'd according to the Rules of Art? whoſe make ſhould comply with the Laws of *Sonorous Motion* (which that does not) and therefore not ſo much *Refract*, as to alter and confound the *Tone* of *the Voice* and Words (as that ſomewhat does.)

Now of what uſe ſuch an Inſtrument might be for ſpeaking clearly and articulately at a diſtance (and that without altering the Tone of the Voice) whether it be at Sea or at Land (but eſpecially at Sea in tempeſtuous Weather and in the Night) is obvious to any Man to conceive.

2. As Inſtruments have been invented to help the Eye, So likewiſe are there ſome, and more ſuch there may be for the Ear.

For,

1. As *Spectacles* and other *Glaſſes* are made to help the *Purblind* and weak *Eyes*, to ſee at any competent diſtance: So there are *Otacouſticks* (and better may be made) to help weak *Ears* to hear at a reaſonable diſtance alſo. Which would be as great a help to the infirmity of Old Age, as the other invention of Spectacles is, and perhaps greater; foraſmuch as the Hearing what's ſpoken is of more daily uſe and concern to ſuch Men, then to be able to *read Books* or to *view Pictures*.

2. As *Perſpective-Glaſſes* and Teleſcopes help the Eye to ſee Objects at a very great diſtance, which otherwiſe would not be diſcernable; in like manner may a ſort of *Otacouſticks* be ſo contriv'd as that they ſhall receive in *Sounds* made at a very great diſtance alſo, but with ſo much advantage, that the Ear ſhall be able to hear them, which otherwiſe would have been *inaudible*.

And theſe *Otacouſticks* in ſome reſpects would be of greater uſe than *Perſpectives*. For whereas at Land *Perſpectives* are many times render'd almoſt uſeleſs, by the interpoſition of Woods and Mountains, which hinder the Sight from reaching very far: Our *Otacouſticks* would, notwithſtanding theſe Obſtacles, take in a Sound made ſome Leagues off. Which might be of notable uſe in the time of War, for diſcovering the Enemy at a good diſtance, when he marches or lyes incamp'd behind a Mountain or Wood, or any ſuch place of ſhelter.

Yea even at Sea alſo, where *Perſpectives* are of moſt uſe, by reaſon of the plaineſs of the Surface of the Water; yet ſometimes there *Otacouſticks* may be of more benefit, when in dark hazy Weather the Air is too thick, or in Stormy Tempeſtuous Weather the Waves a riſe too high for the *Perſpective* to be made uſe of.

But whether at Sea or Land *Perſpectives* become altogether inſignificant in the Night-time (unleſs it be for viewing the Stars) which is the chief time for uſing *Otacouſticks*; as it is generally, for Souldiers to take their March, when they would ſurpriſe their Enemies.

And therefore this ſort of *Otacouſticks* have then their chief uſe, when *Perſpectives* are of no uſe at all; beſides that they may be imploy'd in the Day-time, as well as *Perſpectives*, whence they may (not unfitly) be term'd *the moſt uſeful Inſtrument* of the two.

3. As *Miſcoſcopes* or *Magnifying-Glaſſes* help the Eye to ſee near *Objects*, that by reaſon of their ſmallneſs were *Inviſible* before; which Objects they Magnify to a ſtrange greatneſs: So *Microphones* or *Micracouſticks*, that is Magnifying Ear Inſtruments may be contriv'd after that manner, that they ſhall render the moſt minute Sound in nature diſtinctly audible, by Magnifying it to an unconceivable loudneſs.

By the help hereof we may here the different Cries and Tones, as well as by *Microſcopes* ſee the divers Shapes and Figures of the ſmalleſt Animals.

4. As by *Polyſcopes* or *Multiplying-Glaſſes*, one thing is repreſented to the Eye as many, whether in the ſame or different Shapes (for ſo Multiplying-glaſſes may be contriv'd:) So by a *Polyphone* or *Polyacouſtick* well order'd one *Sound* may be heard as many, either of the ſame or a different Note. Inſomuch, that who uſes this Inſtrument, he ſhall, at the Sound of a ſingle Viol, ſeem to hear a whole Conſort and all true Harmony. By which means this Inſtrument has much the advantage of the *Polyſcope*.

And thus much may ſuffice for compairing the Improvenments made upon *Refracted Seeing and Hearing*; I call it *Refracted Hearing*, becauſe made throngh a *Medium*, viz. thick Air or an Inſtrument, through which the Sound paſſing is broken or refracted.

III. *Reflected Viſion* has been improv'd by the Invention of *Looking-glaſſes* and *Poliſh'd Metals*, whether *Plane*, *Concave*, or *Convex*; and theſe two laſt, either *Spherical*, *Oval*, *Cylindrical*, *Conical*, *Hyperbolical*, or of ſeveral other ſhapes; all which cauſe a different Reflection, and vary the *Phænomena*.

Thus alſo *Reflex'd Audition*, made by *Ecchoes*, may be improv'd, by contriving ſeveral ſorts of *Artificial Ecchoes*; as 'tis no hard matter to do in almoſt any place.

For (ſpeaking in the general) *Any Sound, falling directly or obliquely upon any denſe Body, of a ſmooth (whether Plane or Arch'd) Superficies, is beat back again and reflected, or does eccho more or leſs.*

I ſay (1.) *falling directly or obliquely*; becauſe, if the Sound be ſent out and propagated *parallel* to the Surface of the *Denſe Body*, or be made ſo *far off* and ſo *weak*, that it cannot reach it, there will be no reflection of Sound, no *Eccho*.

I ſay (2.) *upon a Body of a ſmooth Superficies*; becauſe if the Surface of the *Corpus Obſtans* be uneven, the Air by reverberation will be put out of its regular Motion, and the Sound thereby broken and extinguiſh'd: So that tho' in this caſe alſo the Air be beaten back again, yet Sound is not reflected, nor is there any Eccho.

I ſay (3) *it does eccho more or leſs*, to ſhew, that when all things are, as is before deſcrib'd, there is ſtill an Ecchoing, though it be not always heard; either becauſe the *direct Sound* is too weak to be beaten quite back again to him that made it; or that it does return home to him, but ſo weak, that without the help of a good *Otacouſtick* it cannot be diſcern'd; or that he ſtands in a wrong place to receive the reflected Sound, which paſſes over his head, under his Feet, or to one ſide of him; which therefore may be heard by a Man ſtanding in that place, where the reflected Sound will come, provided no interpos'd Body does intercept it; but not by him, that firſt made it.

I ſhall further make out the compariſon 'twixt *Reflex'd Viſion* and *Audition*, by theſe following *Propoſitions.*

1. As a *Plane Speculum* reflects the *Object* in its due *Dimenſions* and *Colours*; allowing for their difference of appearance according to their diſtance: So a *Plane Corpus Obſtans* reflects the *Sound* back in its due *Tone* and *Loudneſs*; if allowance be likewiſe made for the proportionable decreaſe of the Sound according to its diſtance.

2. As a *Convex Speculum* reflects the Object *leſs*, but ſomewhat *brighter* or clearer: So a *Convex Corpus Obſtans* repels the Sound (inſenſibly) *ſmaller*; but ſomewhat *quicker* (though *weaker*) than otherwiſe it would be.

3. As a *Concave Speculum* reflects the Object *bigger*, more *obſcure* and *Inverted*: So a *Concave Corpus Obſtans* ecchoes back the Sound (inſenſibly) *bigger*, *ſlower* (though *ſtronger*) and alſo *inverted*; but never according to the order of Words. Nor do I think it poſſible for the Art of Man to contrive a *Single Eccho*, that ſhall invert the Sound and repeat backwards; becauſe then the Words laſt ſpoken, that is, which do laſt occurr to the *Corpus Obſtans*, muſt firſt be repell'd; which cannot be: For where in the mean time ſhould the firſt Words hang, and be conceal'd, or lie dormant? Or how, after ſuch a pauſe, be reviv'd and animated again

into Motion? Yet in complicated or *Compound Ecchoes*, where many receive from one another, I know not whether ſomething that way may not be done.

From the determinate *Concavity* or *Archedneſs* of theſe reflecting Bodies, it comes to paſs, that ſome of them, from a certain diſtance or poſiture, will eccho back but one determinate Note, and from no other place will they reverberate any; becauſe of the undue Poſition of the ſounding Body. Such an one (as I remember) is the Vault in *Merton* College in *Oxford*.

4. As a *Speculum* takes in and reflects more of its Object, when plac'd at a great diſtance from it, than when nearer; becauſe it reflects according to the apparent Magnitude of the Body at ſuch a diſtance, which is leſs: So alſo the *Eccboing Body*, being removed farther off, reflects more of the Sound, than when nearer. And this is the reaſon, why ſome Ecchoes repeat but one Syllable, ſome one Word, and ſome many.

5. As *Specula's* may be ſo plac'd, that reflecting one upon or into the other, either directly or obliquely, one Object ſhall appear many; as in Sir *Samuel Moreland*'s Glaſs-room: After the ſame manner *Ecchoing Bodies* may be ſo contrived and plac'd, as that reflecting the Sound from one to the other, either directly and mutually, or obliquely and by Succeſſion, out of one Sound ſhall many Ecchoes be begotten; which in the firſt caſe will be all together, and ſomewhat involv'd or ſwallow'd up of each other, and thereby confus'd (as a Face in Looking-glaſſes obverted) in the other they will be diſtinct, ſeparate, and ſucceeding one another; as moſt *multiple Ecthoes* do.

Moreover a *Multiple Eccho* may be made, by ſo placing the *Ecchoing Bodies*, at unequal diſtances, that they reflect all one way, and not one on the other; by which means a manifold ſucceſſive Sound will be heard (not without aſtoniſhment) one clap of the hands like many, one ha like a laughter, one ſingle word like many of the ſame tone and accent, and ſo one Viol like many of the ſame kind imitating each other.

Furthermore, as *Specula's* may be ſo order'd, that by Reflection they ſhall make one ſingle thing appear many different things; as one ſingle Man to ſeem many Men, differing as to ſhape and Complexion (or a company of Men) which I think Sir *Samuel Moreland*'s Contrivance does not: So may *Ecchoing Bodies* alſo be order'd, that from any one Sound given, they ſhall produce many Ecchoes, different both as to their *Tone* and *Intenſion*. (The ground whereof has elſewhere been laid down in a Treatiſe concerning the *Sympathy of Lute-ſtrings.*)

By this means a *Muſical Room* may be ſo contriv'd, that not only one Inſtrument, play'd on in it ſhall ſeem many of the ſame *ſort* and *ſize*; but even a Conſort of (ſomewhat) different ones; only by placing certain *Ecchoing Bodies* ſo, as that any Note (play'd) ſhall be return'd by them in 3ds, 5ths, and 8ths, which is poſſible to be done otherwiſe than was mention'd before in *Refracted Audition*.

I have now done with my *Compariſon* of the two Nobleſt *Senſes* and *Sciences*, as to their *Improvements*; wherein I have been thus large, that I might give you a little proſpect into the *Excellency* and *Uſefulneſs* of *Acouſticks*; and that thereby I might excite all that hear me, to bend their Thoughts towards the making of Experiments for the compleating this (yet very imperfect, though noble) Science; a *Specimen* whereof I will give you in three *Problems*, and then preſent you with the *Semiplane* of *an Acouſtick or Phonical Sphere*, as an Attempt to explicate the great *Principle* in this Science, which is *The Progreſſion of Sounds.*

The Problems are theſe :

1. *Sonum intendere quouſque velis* ; or, *Datum ſonum ad datum gradum intendere.*

2. *Sonum extendere quouſqus velis* ; or, *Datum ſonum ad datam diſtantiam extendere ſeu propagare.*

3. *Sonum tranſire ab extremo ad extremum & non per Medium.*

1. The firſt is, *To make the leaſt Sound* (by the help of Inſtruments) *as loud as the greateſt* ; a whiſper to become as loud as the ſhot of a Canon.

By the help of this *Problem*, the moſt minute Sounds in Nature may be clearly and diſtinctly heard.

2. The ſecond is, *To propagate any* (the leaſt) *Sound to the greateſt diſtance.*

By the help hereof any Sound may be convey'd to any, and therefore heard at any diſtance, (I muſt add, within a certain, though very large Sphere.)

Moreover , by this means , a *Weather-cock* may be ſo contriv'd, as that with an ordinary blaſt of Wind it ſhall cry (or whiſtle) loud enough to be heard many Leagues : Which happily may be found of ſome uſe, not only for *Pilots*

lots in mighty tempeſtuous Weather, when *light Houſes* are render'd almoſt uſeleſs; but alſo for the meaſuring the ſtrength of Winds, if allowance be made for their different moiſture. For I conceive, that the more dry any Wind is, the louder it will whiſtle *cæteris paribus*; I ſay, *cæteris paribus*, becauſe, beſides the ſtrength and and dryneſs of Winds or Breath, there are a great many other things (hereafter to be conſider'd) that concur to the increaſe or magnifying of Sounds, begotten by them in an Inſtrument expoſed to their violence, or blown into.

3. The third *Problem* is, *That a Sound may be convey'd from one extreme to the other* (or from one diſtant place to another) *ſo as not to be heard in the middle.*

By the help of this *Problem* a Man may talk to his Friend at a very conſiderable diſtance, ſo that thoſe in the middle ſpace ſhall hear nothing of what paſſed betwixt them.

FIG. V. TAB. III. p.286

Semiplanum Sphæræ Phonicæ ſeu Acouſticæ.

You are to conceive that (rude) *Semiplane*, as parallel to the *Horizon*: For if it be perpendicular thereunto, I ſuppoſe the upper extremity will be no longer *Circular*, but *Hyperbolical*, and the lower part of it ſuited to a greater Circle of the Earth. So that the whole *Phonical* Sphere (if I may ſo call it) will be a ſolid *Hyperbola*, ſtanding upon a *Concave Spherical* Baſe. I ſpeak this concerning *Sounds* made (as uſually they are) nigh the

Earth, and whoſe Sonorous *Medium* has a free paſſage every way. For if they are generated high in the Air, or directed one way, the caſe will be different ; which is partly deſign'd in the inequality of that draught.

A

A Diſcourſe concerning the Modern Theory *of* Generation, *by Dr.* George Garden *of* Aberdeen, *being part of a Letter to Dr.* William Muſgrave, *L. L. D. Reg. Soc. S. and by him communicated to the Royal Society.*

THE Subject I pitch upon, is that of the Formation of Animals. You know how wide and unſatisfying Mens Conjectures were upon this Head, until this Age, in which firſt the deſervedly Famous Dr. *Harvey* diſcovered the proper place of the Formation of the Chick in the *Cicatricula* of the Egg, and the Formation of the Parts ſo far as was diſcernable by the naked Eye; and after him *Malpighius*, by the help of exact Glaſſes, obſerved the firſt Rudiments of it there, both before and after Incubation: And *R. de Graef*, and others, having upon many Obſervations concluded, that the *Teſtes Fœminei* were the Ovaries of Females, and conſequently that all Animals were *ex ovo*; they began from hence to infer, that the Rudiments of each Animal were originally in the reſpective Females, and that the Male contributed only to give a new Ferment to the Maſs of the Blood and Spirits, by which means a ſpirituous Liquor (which the Blood in its ordinary Ferment could not produce) did inſinuate its ſelf into the ſame Ducts and Pores of the Rudiments of thoſe Animals, which were in greateſt forwardneſs in the Ovary, and ſo extend, and enlarge all their Parts, and at laſt bring them to perfection, as Mr. *Perrault* does ingeniouſly diſcourſe in the third Part of his *Eſſais de Phyſique*; till now at laſt *Leowenhoek* has diſcovered an infinite number of *Animalcula in ſemine marium* of all kinds, which has made him condemn the former Opinions about the Propagation of all Animals *ex Ovo.*

Now upon comparing the Obſervations and Diſcoveries which have been made with one another, theſe three things ſeem to me very probable. 1. That Animals are *ex Animalculo.* 2. That theſe Animalcles are originally *in ſemine Marium & non in Fœminis.* 3. That they can never come forward, nor be formed into Animals of the reſpective kind, without the *Ova in Fœminis.*

The firſt of theſe ſeems probable from theſe three Obſervations. 1. That ſome ſuch thing has been ſo often obſerved by *Malpighius*, in the *Cicatricula* of an Egg before Incubation, as the Rudiments of an Animal in the ſhape of a Tadpole, as may be ſeen in his firſt, and in his repeated Obſervations *de formatione Pulli in Ovo.* 2. The ſudden appearance and diſplaying of all the Parts after Incubation, makes it probable, that they are not then actually formed out of a fluid, but that the *Stamina* of them have been formerly there exiſtent, and are now expanded. The firſt Part of the Chick which is diſcovered with the naked Eye, is, you know, the *Punctum ſaliens*, and that not till three days and nights of Incubation be paſt; and then, on the fifth day, the Rudiments of the Head and Body do appear. This made Dr. *Harvey* conclude, that the Blood had a being before any other Part of the Body; and that from it, all the Organs of the *Fœtus* were both form'd and nouriſhed: But by *Malpighius*'s Obſervations we find that the Parts are then only ſo far extended, as to be made viſible to the naked Eye, and that they were actually exiſtent before, and diſcernable by Glaſſes. After an Incubation of thirty hours, are to be ſeen the Head, the Eyes, and the *Carina*, with the *Vertebræ*, diſtinct, and the Heart. After forty hours its Pulſe is viſible, and all the other Parts more diſtinct, which cannot be diſcerned by the naked Eye before the beginning of the fifth day; from whence it ſeems probable, that even the ſo early diſcovery of thoſe Parts of the *Fœtus* by the Microſcope, is not the diſcerning of Parts newly formed, but only more dilated and extended by receiving of Nutriment from the *Colliquamentum*; ſo that they ſeem all to have been actually exiſtent before the Incubation of the Hen. And what *Swammerdam* has diſcovered in the tranſformation of Inſects, gives no ſmall light to this; whilſt he makes appear in the Explanation of the 13th Table of the General Hiſtory of Inſects, that in thoſe large *Eruca's* which feed upon Cabbage, if they be taken about the time they retire to be transform'd into *Aurelia*'s, and plung'd often in warm Water to make a Rupture of the outer Skin, you will diſcern thro' the tranſparency of their ſecond Membrane, all the Parts of the Butterfly, the Trunk, Wings, Feelers, &c. folded up. But that after the *Eruca* is chang'd into an *Aurelia*, none of theſe Parts can be diſcerned, they are ſo drencht with moiſture, tho' they be there actually form'd. Another Conſideration is from the Analogy, which we may ſuppoſe between Plants and Animals. All Vegetables we ſee do proceed *ex Plantula*, the Seeds of Vegetables being nothing elſe but little Plants of the ſame kind folded up in Coats and Membranes; and from hence we may probably conjecture, that ſo curiouſly an organized Creature as an Animal, is not the ſudden Product of a Fluid or *Colliquamentum*, but does much rather proceed from an Animalcle of the ſame kind, and has all its little Members folded up according to their ſeveral Joints and Plicatures, which are afterwards enlarged and diſtended, as we ſee in Plants. Now tho' this Conſideration alone may ſeem not to bear much weight; yet being join'd to the two former they do mutually ſtrengthen each other. And indeed all the Laws of Motion which are as yet diſcovered, can give but a very lame account of the forming of a Plant or Animal. We ſee how wretchedly *Des Cartes* came off when he began to apply them to this Subject; they are form'd by Laws yet unknown to Mankind; and it ſeems moſt probable, that the *Stamina* of all the Plants and Animals that have been, or ever ſhall be in the World, have been formed, *ab Origine Mundi*, by the Almighty Creator within the firſt of each reſpective kind. And he who conſiders the Nature of Viſion, that it does not give us the true magnitude, but the proportion of things; and that what ſeems to our naked Eye but a Point, may truly be made up of as many Parts as ſeem to us to be in the whole viſible World, will not think this an abſurd or impoſſible thing.

But the ſecond thing which later Diſcoveries have made probable, is, that theſe Animalcules are originally *in Semine Marium & non in fœminis.* And this I collect from theſe Conſiderations: 1. That there are innumerable *Animalcula* diſcovered *in Semine Maſculo omnium Animalium.* Mr. *Leewenhoeck* has made this ſo evident by ſo many Obſervations, that I do not in the leaſt queſtion the truth of the thing. The reaſon of their multitude, and ſome of the difficulties which ariſe thereupon, he has cleared to very good purpoſe, ſo that I ſhall not repeat them. 2. The obſerving the Rudiments of the *Fœtus* in Eggs, which have been fecundated by the Male, and the ſeeing no ſuch thing in thoſe which are not fecundated, as appears from *Malpighius* his Obſervations, make it very probable that theſe Rudiments proceed originally from the Male, and not from the Female. 3. The reſemblance between the Rudiments of of the *Fœtus in Ovo*, both before and after Incubation, and the *Animalcule*, makes it very probable that they are one and the ſame. The ſame Shape and Figure which Mr. *Leewenhoeck* gives us of the *Animalcule*, *Malpighius* likewiſe gives of the Rudiments of the *Fœtus*, both before and after Incubation; yea, and even the *Fœtus's* of Animals do appear ſo at firſt to the naked Eye, ſo that Dr. *Harvey* does acknowledge that all Animals, even the moſt perfect, are begotten of a Worm, *De Gen. Anim. Ex.* 18. 4. This gives a rational account of many *Fœtus's* at one Birth, eſpecially that of the Counteſs of *Holland*, and how at leaſt a whole Cluſter of Eggs in a Hen are fecundated by one Coition of the Male. 5. This gives a new light, as it were, to the firſt Prophecy concerning the

Meſſiah, that the Seed of the Woman ſhall bruiſe the Head of the Serpent, all the reſt of Mankind being thus moſt properly and truly the Seed of the Man. 6. The Analogy I have already mentioned, which we may rationally ſuppoſe between the manner of the propagation of Plants and Animals, does likewiſe make this probable. Every Herb and Tree bears its Seed after its kind; which Seed is nothing elſe but a little Plant of the ſame kind, which being thrown into the Earth, as into its *Uterus*, ſpreads forth its Roots and receives its nouriſhment, but has its form within its ſelf, and we may rationally conjecture ſome ſuch Analogy in the Propagation of Animals.

The third Particular which later Diſcoveries make probable, is, that Animals cannot be form'd of theſe *Animalcula* without the *Ova in fœminis*, which are neceſſary for ſupplying of them with proper Nutriment: And this theſe Conſiderations ſeem to evince. 1. It is probable that an Animalcule cannot come forward, if it do not fall into a proper *Nidus*. This we ſee is the *Cicatricula* in Eggs; and tho' a Million of them ſhould fall into an Egg, none of them would come forward, but what were in the Center of the *Cicatricula*; and perhaps the *Nidus* neceſſary for their formation is ſo proportion'd to their bulk, that it can hardly contain more than one Animalcule; and this may be the reaſon why there are ſo few Monſters. This we ſee is abſolutely neceſſary in *Oviparis*; and the only difference which ſeems to be between them and the *Vivipara*, in this matter, is in this, that in the latter the *Ova* are properly nothing more but the *Cicatricula*, with its *Colliquamentum*, ſo that the *Fœtus* muſt ſpread forth its Roots into the *Uterus* to receive its nouriſhment; But the Eggs in *Oviparis* may be properly term'd an *Uterus*, in relation to the *Fœtus*; for they contain not only the *Cicatricula*, with its *Amnion* and the *Colliquamentum*, which is the the immediate nouriſhment of the *Fœtus*, but alſo the materials which are to be converted into that *Colliquamentum*; ſo that the *Fœtus* ſpreads forth its Roots no farther than into the white and yolk of the Egg, from whence it derives all its nouriſhment. Now that an Animalcule cannot come forward without ſome ſuch proper *Nidus*, Mr. *Leewenhoeck* will not readily deny; for if there were nothing needful, but their being thrown into the *Uterus*, I do not ſee why many hundreds of them ſhould not come forward at once; for as to what Mr. *Leewenhoeck* ſays, that one of them would be-dwarf and choak the reſt; this might fall out in proceſs of time: But at firſt I do not ſee why many of them ſhould not grow together; whilſt ſcatter'd in ſo large a Field (and yet no ſuch thing is obſerved) if there were not an abſolute neceſſity of a *Cicatricula* for their growth and thriving. Now, 2. That this *Cicatricula* is not originally in *Utero*, ſeems evident from the frequent Conceptions which have been found *extra Uterum*: Such as the Child which continued Twenty ſix years in the Woman of *Tholouſe*'s Belly, mentioned *Numb.* 139. of the *Phil. Tranſ.* And the little *Fœtus* found in the *Abdomen de St. Mere*; together with the Teſticle torn and and full of clotted Blood, recorded *Numb.* 150. both taken out of the Journals *des Scavans*: Such alſo ſeem to be the *Fœtus* in the *Abdomen* of the Woman of *Copenhagen*, mentioned in the *Nouvelles des Lettres*, for *Sept.* 85. *pag.* 996. all the Members of which were eaſily to be felt thro' the Skin of the Belly, and which ſhe had carried in her Belly for four Years; and the ſeven Years Gravidation, related by Dr. *Cole*, *Numb.* 172. of the *Tranſact.* That theſe two were undoubtedly *extra Uterum*, is uncertain, becauſe the laſt was not opened after her death, and the former may be yet ſtill alive. Now granting once the neceſſity of a proper *Nidus*, for the formation of an Animalcle into the Animal of its reſpective kind; theſe Obſervations make it probable, that the *Teſtes* are the *Ovaria* appropriated for this uſe; for tho' the Animalcles coming thither in ſuch Caſes may ſeem to be extraordinary, and that uſually the Impregnation is *in Utero*; yet it may be collected from hence, that the *Cicatriculæ* or *Ova* to be impregnated, are in *Teſtibus fœmineis*; for if it were not ſo, the accidental coming of Animalcles thither could not make them come forward more than in any other part of the Body, ſince they cannot be formed and nouriſhed without a proper *Nidus*. But 3. It is acknowledg'd by all, that the *Fœtus in Utero*, for ſome conſiderable time after Conception, has no connexion with the Womb, that it ſits wholly looſe to it, and is perfectly a little round Egg with the *Fœtus* in the midſt, which ſends forth its Umbilical Veſſels by degrees, and at laſt lays hold on the *Uterus*. Now from hence it ſeems evident, that the *Cicatricula*, which is the Fountain of the Animalcles nouriſhment, does not ſprout from the *Uterus*, but has its *Origin* elſewhere, and falls in thither as into a fit Soil, from whence it may draw Nutriment for the growth of the *Fœtus*; elſe it cannot be eaſily imagin'd, how it ſhould not have an immediate

Connexion with the *Uterus* from the time of Conception. If you join all theſe three Conſiderations together, *viz.* that an Animalcule can- 1 not come forward without a proper *Nidus* or *Cicatricula*; that there have been frequent *Fœ-* 2 *tus's extra Uterum*; and that they have no *Adhæſion* to the *Uterus*, for a conſiderable time af- 3 ter Conception, they ſeem to make it evident, that Animals cannot be form'd *ex Animalculis* without the *Ova in Fœminis*. To all theſe I ſhall ſubjoin the Propoſal of an *Experimentum Crucis*, which may ſeem to determine, whether the *Teſtes Fœmineæ* be truly the *Ovaria*, *viz.* Open the *Abdomen* of the Females of ſome kinds, and cut our theſe Teſticles, and this will determine, whether they be abſolutely neceſſary for the formation of Animals.

There are ſome Difficulties propoſed againſt this Conjecture, which I think may be eaſily reſolved. Some object the diſtance between the *Tubæ* or *Cornua Uteri*, and the Teſticles, but to this is oppoſed by *Swammerden*, and others, the like diſtance between the *Infundibulum*, in Hens and Frogs, and the Ovary; and yet it cannot be denied that the Eggs are tranſmitted thro' this into the *Uterus:* and beſides *R. de Graef*, and others, have by repeated Obſervations found that the *Cornua Uteri* do at certain times after Conception, embrace the *Teſtes* on both ſides the *Uterus.* They object in the ſecond place the great diſproportion between the pretended Eggs in the Ovary, and the Aperture of the *Tubæ* or *Cornua Uteri*, the former being a great deal bigger than the latter: But both *R. de Graef* and *Malpighius* have clear'd that Matter, by making appear, that theſe Bladders in the Ovary are not the *Ova*, but ſerve to form the *Glandules* within which the *Ova* are formed, which break through a ſmall *Papilla* opening in the *Glandule*, which bears a proportion to the Aperture of the Tube. They object 3. The difficulty to conceive how theſe Eggs ſhould be impregnated *per ſemen Maris*, both becauſe there is no Connexion between the *Tubæ* and the Ovary for its tranſmiſſion, and for that Dr. *Harvey* could never diſcover any thing of it in *Utero*. As to the laſt, Mr. *Leewenhoeck* has cleared that difficulty, by the diſcovery of innumerable *Animalcula Seminis Maris in Cornnbus Uteri*, and thoſe living a conſiderable time after Coition. *Numb.* 174. of the *Tranſact.* And as to the former, we may either ſuppoſe that there is ſuch an Inflation of the *Tubæ* or *Cornua uteri tempore Coitionis*, as makes them embrace the *Ovaria*, and ſuch an approach of the *Uterus* and its *Cornua*, as that i may eaſily tranſmit the Seed into the Ovary; or elſe, that the *Ova* are impregnated by the Animalcles after they deſcend into the *Uterus*, and not in the Ovary; the former ſeems probable for this reaſon, that at leaſt a whole Cluſter of Eggs in a Hen will be fecundated by one Tread of the Cock: Now this Fecundation ſeems to be in the Vitellary, and not in the *Uterus*, as the Eggs paſs along from day to day; for it can hardly be ſuppoſed that the Animalcles ſhould ſubſiſt ſo long, being ſcattered looſely in the *Uterus*, as to wait there for many days for the Fecundation of the Eggs as they paſs along. The latter conjecture has this to ſtrengthen it, that the Animalcles are found to live a conſiderable time in the *Uterus*; and that if they ſhould impregnate the *Ova* in the Ovary its ſelf, the *Fœtus* would increaſe ſo faſt, that the *Ova* could not paſs thro' the *Tubæ Uteri*, but would either burſt the Ovary, or fall down into the Abdomen from the Orifices of the *Tubæ*; and that from hence proceed thoſe extraordinary Conceptions in *Abdomine extra Uterum*. But, 4. Mr. *Leewenhoeck*, *Numb.* 147. of the *Tranſact.* to weaken the third Conſideration about the Conceptions, being like unto an *Ovum* in the Womb, propoſes a Parallel between theſe Animalcules and Inſects; and inſinuates, that as the latter caſt their Skins and appear of another Shape, ſo the other which at firſt ſeem like Tadpoles, may caſt their outer Skin and and then be round, and that this may be the occaſion of the round Figure of the Conception in the Womb. To this it may be replied, that according to Mr. *Leewenhoeck*'s own Sentiment, the Animalcles cannot come forward, if they do not find the *Punctum* or proper place for their Nouriſhment, to which it ſeems they muſt have ſome *Adhæſion*. Now the Conception in *Viviparis* is not faſtned unto the Womb for many days, nor does adhere to any point of it; ſo that it ſeems this roundiſh Body is not the Animalcle thus chang'd after having caſt an outer Skin, but is rather the *Cicatricula* or little Egg, into which the Animalcle has entred as its *Punctum* or place of Nouriſhment; elſe I do not ſee why they ſhould not be adhering to the Womb from the firſt Conception, or why (as I have ſaid) many hundreds of them are not conceived and formed together, *&c.*

A ſhort Diſcourſe concerning Concoction: Read at a Meeting of the Royal Society, May 1699, *by* Clopton Havers, *M. D. Fellow of the Royal Society.*

THE manner in which the Digeſtion of the Aliment is performed, is a thing not very eaſie to be underſtood and explain'd. However, it has not eſcap'd the Conjectures of ſome Philoſophical Men, who having curiouſly obſerv'd the *Phænomena* of Nature, and enquired into their Cauſes, have, amongſt other things, endeavour'd to account for this. But their Sentiments about it have been various, and the Hypotheſis, by which they have ſtudied to explain it, very different. Some have thought the Concoction of the Food to be a kind of Elixation; and that the groſſer and more ſolid Parts being, as it were, boil'd in the Liquid by the Heat of the Stomach, and the Parts adjacent to it, as the Liver, Spleen, and Omentum, are by a long and continued Elixation firſt render'd more tender, and then colliquated, and diſſolved into minuter Particles, ſo as to mix more equally with the fluid, and with that to make one Pulpament, or chylous Maſs. And *Hippocrates*, tho' he does not plainly call it an Elixation, yet ſeems to attribute the Concoction of the Food to the Heat of the Stomach, as the Cauſe of it, *Sect.* 4. *Libro de Salubri victus ratione.*

ratione. So where he takes notice of the voiding of ſuch Fœces, as appear to be like the Food that has been eaten, he adds, *Conſtat enim, ſane ventriculum, ciborum copiam, ut concoquat, calefacere non poſſe.* And there are other Paſſages in the ſame Book, from which we may conclude, that he ſuppos'd the Heat of the Stomach to be the great Cauſe of the Digeſtion of the Food.

There are others that make the Stomach it ſelf to be the great Inſtrument of Digeſtion, but in a different manner: And they ſuppoſe it to be perform'd by an Attrition, as if the Stomach, by thoſe repeated motions, which are the neceſſary Effects of Reſpiration, when it is diſtended by the Aliment, did both rub or grind off ſome minuter Particles from the groſſer Parts, and by continually agitating the Maſs of Food, make thoſe Parts, which are not contiguous to the Stomach, ſtrike one againſt another, and break one another in pieces, until they are all attenuated. It is evident enough, that the ſides of the Stomach do in Expiration preſs upon the Contenta, ſo as to oblige, at leaſt ſome Parts of them, every time the Muſcles of the Abdomen are contracted, to move and ſhift their places. So in Inſpiration, when the Diaphragm and Liver preſs upon the upper part of the Stomach, the Aliment muſt be moved again. So that by theſe reciprocal motions, that part of the Food which is contiguous to the Stomach, and moves in a Line parallel to it, muſt rub againſt it; and all the other Parts being moved by ſuch a Compreſſion, as gives them a different Tendency, it is certain they muſt be continually ſtriking one againſt another. And for Bread, and ſuch things as are made of Flower, that will be ſoften'd and diſſolv'd with any common Liquid, that Agitation of the Stomach which moves them in Reſpiration, might ſeem ſufficient to break and diſſolve them, when they are ſufficiently moiſten'd with a Fluid. Yet this cannot be thought enough to break and digeſt Fleſh-meat, Fruits, or any other thing that will not be ſoftned and diſſolv'd in Water, or ſome ſuch Liquid. But altho' this Motion of the Aliment, cauſed by Reſpiration, does not actually digeſt it, yet it has a great and neceſſary Uſe in Concoction, and makes all the groſſer Parts, as they are attenuated, mix equally with the Fluid.

Some think that the Bilious Juice; others, that the Spirits are chiefly concern'd in this Affair. *Galen*, in his Book *de Naturalibus Facultatibus*, makes it to be the Effect, not of one, but of ſeveral Cauſes; as a pituitous Juice in the Stomach, the Bile, *&c.* which appears from what he has ſaid, and the Tranſlator thus render'd: ' *Verum quanto ii (cibi) qui manſi ſunt, iis, qui* ' *inhæſerunt, magis ſunt alterati; tanto etiam his* ' *magis ii, qui devorati ſunt. Siquidem incompa-* ' *rabilis erit horum alterationis exceſſus, ſi & quæ* ' *in ventre eſt Pituita & Bilis, & Spiritus, & Ca-* ' *lor, & tota Ventris ſubſtantia, æſtimentur.*

Some there are that will have the Food to be diſſolv'd by a Menſtruum, which is ſupply'd from the Glands of the Stomach, or ſome other way: But thoſe that do ſo far agree in the General, as to think Concoction is perform'd by a Diſſolvent, do differ in their Notions of the Nature of the Menſtruum: For there are ſome that ſuppoſe it to be an Acid, which does erode the groſſer Parts of the Food, and diſſolves them in the ſame manner as Vinegar, Spirit of Vitriol,

triol, or any ſuch-like Acid, will diſſolve even ſo ſolid a Body as Iron. And it cannot be deny'd, but that Oil of Vitriol will diſſolve Fleſh-meat, and reduce it to a Pulp; but it is not to be ſuppos'd, that the Fibres of the Stomach can admit any ſuch ſtrong and corroding Acid, without ſomething to correct it, but it muſt be injur'd in its Tone, and labour under great and extraordinary Pains. Neither does ſuch a Menſtruum, tho' it will digeſt ſome things, ſeem capable of diſſolving ſo great a Variety of Things as we eat, eſpecially when a great many of them are of a contrary Nature. Some will have the Menſtruum to be a *nitro-aerius* Spirit, that is, quick, and very penetrating, and included in its proper Vehicle; which, being in its own Nature apt to penetrate the Maſs of the Aliment, does diffuſe it ſelf through the Whole, and breaking the Vinculum of the more ſolid Parts, does diſſolve their Compages. By others, it is thought to be ſome ſaline Juice in the Stomach, by which the Parts of the Aliment are divided and diſſolved, and thoſe which are fit for Nouriſhment, are volatiliz'd.

Laſtly, There are ſome others who reject the Opinions I have already mention'd, and ſuppoſe the Digeſtion of the Food to be perform'd by the Benefit of a Ferment; which, when it is mix'd with the Aliment, excites in the Maſs an inteſtine motion; and the different and contrary motions or tendency of the Parts making ſome kind of Colliſion, gradually break off Particles from the groſſer, and more ſolid Parts, 'till they are ſo attenuated as to be apt to mix more equally with the Fluid, and with them to make one ſoft or chylous Subſtance. But yet there is not amongſt them an univerſal Conſent,

ſent, either about the Nature of this Ferment, or the manner how it is ſupply'd. For firſt, ſome think it to be the Remains of the Food that was laſt digeſted; which having lain ſome time in the Stomach, after the reſt is carried down into the Inteſtines, contracts an Acid, or ſome other Quality, and is ſo alter'd as to partake of the Nature of a Leaven. And this Leaven being a part of the Food, which has been already digeſted, is ſo ſoft and liquid as to be capable of mixing with the Aliment, which is next taken into the Stomach; and being agitated with it by the repeated Preſſures of the Diaphragm, Liver,and Abdominal Muſcles upon the Stomach in Reſpiration, does diffuſe it ſelf through the whole Maſs; and being mixed with it, like Leaven, or Yeſt added to new Wort, *&c.* puts it into a State of Fermentation; and by this Fermentation, or the Expanſion of the Ferment, and the more tenuious Parts, which are firſt put into motion by it, thoſe which are more ſolid, and with which they are intermix'd, are rent, and divided, and ſo attenuated, as to become a ſoft and pulpous matter. And altho' the greateſt part of the Food, that is thus broken and concocted, is by the Contraction of the Fibres of the Stomach preſs'd into the Duodenum; yet they do not contract themſelves ſo as to force out all the Aliment, but leave between the *Rugæ* or Folds, on the inſide of the Stomach, a ſufficient Quantity to be a Leaven to the next Meal; and ſo from time to time.

Some have a Notion, That this Ferment, or Principle of Fermentation, is in the Aliment it ſelf; which being a Congeries of Matter, conſiſting of various Parts of a different Nature, is no ſooner encloſed in the Stomach, and digeſted in the Heat of that, and the adjacent Parts, but the more ſpirituous and ſubtil Particles are put into motion both from that Warmth, and the difference of their Natures, and enter upon a Fermentation. And ſo by their inteſtine Commotion, and the Violence they offer to thoſe Parts which oppoſe the tendency of any of them, they break and diſſolve what is more ſolid.

Again: Some ſuppoſe, that this Ferment is ſupply'd from the Glands of the Stomach.

And Laſtly, Others, and perhaps with much better Reaſon, contend for the Saliva, and make that to be the Ferment, which ſerves principally for the Digeſtion of the Food; which in Maſtication being mix'd with our Aliment, is with that carried down into the Stomach, where the Parts of it being put into motion by a kindly and agreeable Heat, they do ferment with, and exagitate firſt thoſe Parts of the Food which are moſt apt to ferment with it, and then both conſpire to break and diſſolve the groſſer and more ſtubborn Parts. And *Galen*, in the Book I have before-mentioned, plainly allows that the *Saliva* is concerned in the buſineſs of Concoction, tho' he ſuppoſes the Alteration, which is produc'd by this Juice, to be made in the Mouth, as appears from theſe Words: *Qua (alteratio) in ore agitur mutat quidem id (nutrimentum) in alteram ſpeciem manifeſte, non tamen ad perfectionem tranſmutat ---- Qui manſi ſunt cibi primum quidem hac Pituita (oris) inbuuntur, & cum ea miſcentur ---- Itaque majorem mutationem conſecuti ſunt, quam ii, qui in vacuis dentium intervallis fuere impacti.*

Now I have given this ſhort Account of the various Opinions of ſome Ingenious Men, concerning the manner how Concoction is perform'd; I come now to propoſe my own Hypotheſis, by which I ſhall endeavour to explain it.

In order to the more eaſie and effectual Digeſtion of the Food, Nature has appointed ſome Parts for the breaking our Aliment, and reducing whatever is groſs into ſmaller Parts, before it is put upon Digeſtion: Others to ſupply the Ferment, by which it is to be diſſolv'd and concocted, and which, before it comes to be included in the Stomach, does moiſten, and make it more ſoft, that it may more eaſily be penetrated and broken by thoſe Parts which ſerve to divide every Morſel into ſmaller Pieces, and prevents the Inconvenience and Trouble which would ariſe from the Nouriſhment ſticking about or between them, when it is dry or viſcous.

For the breaking of that part of our Food, which is not liquid, Nature has furniſh'd us with Teeth, and thoſe of two ſorts: For ſome are ordain'd to divide and break off ſmaller Morſels from a larger Maſs; others are made for the grinding thoſe Morſels into much ſmaller parts. The Teeth, which ſerve to break off Pieces of a convenient Magnitude from a larger Maſs, are of two ſorts accommodated to the Nature of the Subſtance which we eat. Theſe are the *Inciſores*, and the *Dentes Canini*. If the Subſtance, which we have to eat, be not hard, but more eaſily penetrated and divided, then the *Inciſores* are capable of making an Impreſſion upon it, and fix'd firmly enough in the

Jaws to break off that part which they take hold of. But if it be more ſolid, and not eaſily penetrated, nor any Piece without difficulty to be ſeparated from that Body, whereof it is a part; then we apply the *Dentes Canini*, or Eye-Teeth to it, which are not ſpread, nor have ſuch an edge as the *Inciſores*, but are ſharp and pointed like an Awl, and ſo do more readily penetrate a Subſtance that is hard, and which the *Inciſores* can ſcarcely make any Impreſſion upon. And as the Parts of a more ſolid Body are commonly with more difficulty ſeparated, and there muſt be a greater ſtreſs put upon thoſe Teeth which pull it into pieces; ſo theſe Teeth are much more firmly fixed in the Jaws than the *Inciſores*, tho' they have but one ſingle Root. Beſides, the Poſition of all theſe Teeth is accommodated to their uſe, as being planted oppoſite to the Aperture of the Mouth; ſo that they may be conveniently apply'd to the Subſtance which we have to eat, before it is broken, and when it is too large to be admitted within the Mouth.

The Teeth which do by a Compreſſion and Attrition reduce the little Morſels to ſmaller Parts, are from the manner in which they break the Aliment, called *Dentes Molares*, becauſe they do, like ſo many Mill-ſtones, grind the Food between them. And that they might be render'd fit for this purpoſe, they are made broad at that Extremity, which ſtands out of the Gums, by which means they retain ſome Quantity of the Food between them every time the lower Jaw is pulled up and forc'd againſt the *Maxilla ſuperior*. And as they are broad, ſo they are formed with Inequalities and Protuberances; and by the motion of the lower Jaw, from one ſide towards the other, they grind what they have between them into pieces. The Poſition of theſe Teeth too is as convenient as that of the *Inciſores*, and the *Dentes Canini*: For being deſign'd to break thoſe pieces of our ſolid Food, which are taken into the Mouth, and theſe pieces, when they are compreſs'd, and moved by the *Dentes Molares*, being apt to fly out of the Mouth, if there were no Contrivance to prevent it, they are placed beyond the Aperture of the Mouth, and oppoſite to the Cheeks, which keep the Food within that Cavity, and not only ſo, but preſs it in between the *Dentes Molares* on one ſide, as the Tongue does on the other, until they have ſufficiently broken and divided it.

At the ſame time, whilſt the *Dentes Molares* are breaking the Food, there flows into the Mouth a ſalival Juice which mixes with it, and not only ſerves to moiſten it, and to render it more apt and eaſie to be divided, but ſeems to be the Ferment, by the Benefit of which the Food is diſſolved and digeſted. And therefore it is intimately mixed with it, by the Teeth agitating or ſtirring them together in maſtication.

This Liquor, which we commonly call the Saliva, or Spittle, ſeems to be a Compoſition made of two ſeveral Juices, very different in their Nature: And therefore the ſeveral Parts of it are ſeparated by their proper Glands, and Nature has planted no fewer than four pair about the Mouth, which ſupply the Juices that make the Saliva; to wit, the *Parotides*, and the *Glandulæ Nuckianæ*, the

Glandulæ Maxillares internæ, and *Sublinguales*. Whereas if the *Saliva* were but one more ſimple Liquor, a leſs number of Glands might have been ſufficient. At leaſt there appears no Reaſon why one of every Pair ſhould diſembogue it ſelf into the Mouth ſo very near to the Orifice, by which a Gland of ſome other Pair throws in its Juice; and they are not rather all planted at more equal diſtances from one another, ſo to flow in upon every part of the Aliment at the ſame time.

Not that I ſuppoſe, as there are four Pair of ſalivatory Glands, ſo there are four ſorts of Juices ſupply'd from them, to make the *Saliva*; but, as I hinted before, that there are only two different Juices that conſtitute it. And theſe are not only ſufficient, but more proper to excite and ſecure that Fermentation, which is neceſſary to Concoction. For we find that moſt of thoſe Fermentations, which ariſe upon Mixtures made for Experiments, are produced from the mixture of two things; and it is not ſo eaſie to find out three or four ſuch Liquors of a different Nature, as will, upon the mixtion of them all, produce a Fermentation, and from the omiſſion of any one of them diſcover no Diſcord or Diſpoſition to ferment: Beſides, it is certain that two do better ſecure the End, which Nature deſigns. For, if there were three or four different Juices, of which the *Saliva* naturally conſiſts, theſe muſt all have their proper Qualities preſerv'd to them, or elſe the Fermentation, which ſhould ariſe between them, will not neceſſarily follow upon their mixture; and it is certain, that there would be more

Danger, that one of three or four ſhould be depriv'd of its natural Quality, than one of two.

What Nature theſe two Juices are of, I do not pretend poſitively to determine; but ſo far as I have been able to make my Conjectures about it from Experiments, I do think one of them to be an acid Juice; the other an oleaginous Liquor, ſomething like Oil of Turpentine. For amongſt the many Experiments I have made, there was no one that gave me ſo much Satisfaction, as that which I made with Oil of Turpentine and Oil of Vitriol, tho' I try'd ſeveral other things, that will produce a Fermentation upon their Mixture. And it was for this Reaſon, that I made the Experiment with Oil of Turpentine and the other Oil.

I took a piece of raw Fleſh, and having cut it into pices, but much larger than what our more ſolid Food is reduc'd to by due Maſtication, I mix'd ſome Crums of Bread with it, then I poured in the Oil of Turpentine to them, and upon that the Oil of Vitriol; and having ſhak'd them together, I digeſted them about four hours in *Balneo Mariæ*, and then ſhaking them again in the Glaſs, I found the Meat diſſolv'd, and they all became a thickiſh Pulp. I could not but take notice, that Oil of Camphire (tho' it does not otherwiſe ſeem much different in its Nature from Oil of Turpentine) and Oil of Vitriol, which upon mixture will produce an efferveſcence as well as the Oil of Turpentine and Oil of Vitriol, yet did not touch the Meat, upon which I poured them, ſo as in the leaſt to diſſolve them. I cannot deny but that an Acid, and a Solution of Salt of Tartar, did diſſolve ſome part of the Fleſh-meat, which I mix'd them with, but yet neither ſo ſoon nor ſo perfectly as the two forementioned Oils. And I do the rather think one of thoſe Juices, which conſtitute the *Saliva*, to be of the Nature of Oil of Turpentine, than of a fix'd Salt, becauſe it will correct and temper even Oil of Vitriol, ſo as to render it more tolerable to the Fibres of the Stomach. Not that I ſuppoſe the acid part of the *Saliva* to come near to the Acidity of Oil of Vitriol. For tho', when they are mix'd, they will make a Liquor that may not be injurious to the Stomach; yet the acid Juice, if it were ſo corroſive as Oil of Vitriol, would certainly be injurious and painful to the ſalivatory Ducts, which convey it to the Mouth before it is mix'd with the oleaginous Liquor. But I only ſay it is an Acid, and in ſome degree approaches to the Nature of that Oil. And Nature, which can much better adapt ſeveral Cauſes for the Production of ſuch an Effect than Art, may attain her End by a more temperate Acid; tho', at the ſame time, we may be able to make ſome probable and true Conjectures about the Nature of thoſe Cauſes from Experiments.

It being moſt reaſonable to ſuppoſe, that there are but two ſorts of Juices, of a different Quality, that make the *Saliva*, I do conceive, that four of the eight ſalivatory Glands, or two pair of the four, do ſupply one of theſe Juices, and the other four Glands the other. And this ſeems to be a very good Reaſon, why they are ſo planted, and the Orifice of their

Ducts ſo order'd, that the Juice, which is ſupply'd by one Gland, is diſcharg'd into the Mouth, very near to the Orifice, by which the Juice of a different Nature is tranſmitted from another, ſo that they muſt neceſſarily meet and mix together. Thus the *Glandulæ Nuckianæ*, and *Parotides*, throw in two different Juices by Orifices, which open into the Mouth very near to one another; and the *Glandulæ Maxillares internæ*, and *Sublinguales*, do below ſupply the ſame kind of Juices by Orifices, that open ſo near to one another as to ſecure the mixture of the two different Juices.

Theſe Glands, I ſay, do between them afford two divers ſorts of Liquors, of ſuch a Nature as are apt to ferment upon their firſt Mixture, but perhaps more conſiderably when they come to be digeſted by the Heat of the Stomach. So that the Colluctation, or Fermentation, which attenuates and concocts the Food in the Stomach, does not ordinarily ariſe between the Aliment and the *Saliva*, but between the ſeveral Parts of the *Saliva* it ſelf. And indeed, if the *Saliva* did not conſiſt of two Juices, whoſe Nature is in ſuch a manner different, as to render them apt to ferment upon their mixture, it would be very hard to conceive how it ſhould ſo readily and indifferently ſerve for the Digeſtion of all Eatables; how it ſhould ferment with, and diſſolve ſo great a Variety of things, not only of a different, but of a contrary Nature; how it ſhould ferment with Acids as well as Alkalies, digeſt things that are cold as well as hot or temperate; ſome things that are ſalt, others that are inſipid, bitter and ſweet, mucilaginous, oily, *&c.* But if we ſuppoſe, that the Fermentation, which ſerves for the Digeſtion of the Food, ariſes from a peculiar difference in the Nature of two Juices, which conſtitute the *Saliva*, it will be eaſie to give a rational Account of our Concoction of innumerable things of a different Nature. And this ſeems to be as effectual, and a more certain way to attenuate and diſſolve the groſſer Parts of our Food, than if the Fermentation were made only between the *Saliva* and the Aliment: Beſides, the *Saliva* ſeems to diſcover a Fermentation upon the mixture of its conſtituent Juices, even at thoſe times when we do not actually eat; for it is always attended with Bubbles, and a Froth, when it has not been at all agitated in the Mouth, and many of thoſe Bubbles will remain for ſome conſiderable time after we have ſpit it out.

Nature therefore having appointed the *Saliva* for the digeſtion of the Food, has taken care that it ſhall be thrown in upon the Aliment on every ſide. Thus the *Glandulæ Nuckianæ*, and the *Parotides*, ſupply their Juices to that part of the Food, which lies on the outſide of the Gums, between the Cheeks and the Teeth, and the *Glandulæ Maxillares internæ*, and *Sublinguales*, do beſtow their Liquor upon the Meat, which is within the Teeth and Gums. Neither has ſhe had a Regard only to that Supply, which is due to all the parts of our Food, but likewiſe to the mixture of the two different Juices of the *Saliva*, which is neceſſary to its Fermentation. And therefore, as I have already obſerv'd, the Orifices

rifices of the Ducts, which belong to one ſort of Glands, are placed near the Aperture of a Duct, which conveys a Juice from one of the other Glands. So the Ducts of the *Glandulæ Nuckianæ*, and the *Ductus Stenoniani*, do on each ſide open into the Mouth, near one another; and the ſalivatory Ducts of the *Glandulæ Sublinguales*, and the *Maxillares internæ*, tho' they have diſtinct Orifices, empty themſelves under the ſame *Papillæ*; and the Juices, which are ſupply'd by them, meet there, and flow into the Mouth together.

The ſeveral Parts of the *Saliva* being diſcharg'd into the Mouth, in ſuch a manner as to meet and begin a Fermentation, the *Saliva* does, partly as it is agitated with the Food by the Teeth, and ſome other parts of the Mouth; partly by its own Fluidity inſinuate it ſelf into, and mixes with the Food, and not only moiſtens and ſoftens it, but excites the Fermentation, which is to diſſolve it. And when the Aliment is thus mix'd with the *Saliva*, which ſerves to ferment the whole Maſs, it is then to be convey'd into the Stomach, that great digeſtive Veſſel of the Body, where the Fermentation is not only continued but improved.

The Nouriſhment being convey'd into the Cavity of the Stomach, is there kept for ſome time in a digeſtive Heat, all which time it is under a Fermentation produc'd by the different Parts or Juices of the *Saliva*, which are mixed with it; which Fermentation does firſt agitate the more tenuious or ſubtil parts of the Food, and puts them into motion, and ſo with the Fermentation of its own, and thoſe

Alimentary Parts, which it firſt communicates a motion to, improv'd by the Heat of the Stomach, the *Saliva* muſt neceſſarily act upon the groſſer Parts. For the inteſtine motion, which is excited in the Maſs, does not give the Particles, which are fermented, the ſame Tendency, but what is ſo various and confus'd, that they muſt inevitably ſtrike not only one againſt another, but againſt thoſe which are more groſs, ſo as to attenuate them, ſometimes by a Colliſion, which ſtrikes off ſmaller Particles from the larger Parts; ſometimes by a Compreſſion, when the Particles which are in motion, happen to ſtrike directly againſt any groſſer Part, on every ſide of it; ſometimes by a kind of Exploſion. For without doubt the *Saliva*, which is fluid, inſinuates it ſelf into the Interſtices of the more craſs Parts of the Aliment, and whatever is agitated and expanded in thoſe Interſtices, requiring a larger ſpace for the Freedom of its motion, and offering a Violence to every thing that oppoſes its Tendency, will, like Gunpowder included in a Shell, force its way out, and tear to pieces that Matter, which does endeavour to confine it.

Thus the groſſer Parts are broken and divided, until they are at laſt ſo far attenuated as to mix more equally with the Fluid, and with them to make one Pulp or Chylous Maſs. And although I do not apprehend how the Stomach ſhould by its reciprocal motions in Inſpiration and Expiration, be able to break and attenuate any Matter, that will not be ſoften'd and diſſolv'd by Agitation in a Liquid; yet it is certain that theſe motions, cauſed by the Diaphragm and Abdominal Muſcles in Reſpiration, do make thoſe Parts, which are broken off, as they are diſſolv'd, mix intimately with the more liquid; as the Meat which I digeſted with Oil of Turpentine, and Oil of Vitriol, did by agitation mix more equally with the Oils, and became a Pulpament.

As the Juices, which conſtitute the *Saliva*, do ferment upon their mixture, ſo it is probable, that from their Mixture and Fermentation there reſults ſuch a *Tertium quid*, as is apt to ferment with the Bile. And therefore, when the Aliment has been under the Fermentation, excited by the *Saliva*, a ſufficient time, it is then thrown into the *Duodenum*, where it meets with the bilious Juice, which flows into that Inteſtine from the Liver, from which a new Fermentation ſeems to begin; and the Commotion of the Parts of the Aliment being ſtill continued, does carry on the Buſineſs of Digeſtion until the Food is perfectly concocted: Tho' it is probable, that this new Fermentation ſerves not only for the more perfect Digeſtion of the Food, but likewiſe for the Separation of the Chyle from the feculent Parts.

Neither do I by a random Gueſs, and an ungrounded Conjecture, ſuppoſe that from the Mixture and Fermentation of the two Juices, which conſtitute the *Saliva*, there reſults a Matter, which is apt to ferment with the Bile. But to me the Notion ſeem'd to be confirm'd by an Experiment that I made. For conſidering with my ſelf, that the Bile is generally allow'd to have much of a ſaponary Nature, I made a Solution of Soap in fair Water, and mix'd it with the Oils of Turpentine and Vitriol firſt put together, and from their Mixture I obſerv'd a very eaſie and gentle Fermentation, which continued for a conſiderable time.

A Diſcourſe concerning ſome Influence of Reſpiration *on the* Motion *of the* Heart, *hitherto unobſerved. By* J. Drake, M. D. F. R. S.

THO' divers accurate Treatiſes of the *Heart*, and its Action, have been written by Learned Men of ſeveral Nations, eſpecially by two of our own Country; the Great Dr. *Harvey*, to whoſe happy Sagacity this Nation owes the Glory of the Invention of the *Circulation* of the *Blood*; and the incomparable Dr. *Lower*, to whom we are beholding for a compleat diſplay of the *Mechanical Structure* of the *Heart*, and a moſt ingenious Rationale of its Action. Yet there remain ſeveral doubts and difficulties about it (in my Opinion) not ſufficiently accounted for, towards the reſolving ſome of which, I ſhall offer what my own Thoughts have ſuggeſted to me, and leave it to the Conſideration of the Reader.

The Learned Dr. *Lower* (whoſe accurate Piece on this Argument will inſure his Reputation ſo long as Phyſical Knowledge ſhall laſt in eſteem) has ſo well accounted for the *Syſtole*, or Contraction of the Heart from the *Mechanical* Structure of it, that he ſeems almoſt to have exhauſted the Subject; and had he been as happy in diſcovering the true cauſe of the *Diaſtole*, he had left little room for the Induſtry and Sagacity of others about this *Viſcus.*

But having judiciouſly and ſolidly explain'd the *Syſtole*, he contents himſelf to aſcribe the *Diaſtole* to a motion of *Reſtitution*, which Account gives me no ſatisfaction: Becauſe the *Syſtole* being the proper, and (as himſelf confeſſes) the only motion of the Heart, a ſtate of *Contraction* ſeems to be the natural ſtate, and conſequently without external violence, it ſhou'd have no *Diaſtole* at all.

This will appear more plain, if we conſider the Circumſtances of it, and its motion, as a Muſcle, with reſpect to other Muſcles. That Contraction is the proper Action, and State of all Muſcles, is evident from Experience of Fact, as well as Reaſon. For, if any Muſcle be freed from the power of its *Antagoniſt*, it is immediately *contracted*, and is not by any Action of the Will, or Spirits, to be reduced to a ſtate of *Dilatation.* Thus, if the *Muſculi Flexores* of any Joint be divided, the *Extenſores* of that Joint being by that means free'd from the contrary Action of their *Antagoniſts*, that Joint is immediately extended without any conſent of the Will, and in that ſtate it remains; and ſo *Vice verſa*, if the *Extenſores* be divided. From whence it is plain, that the Muſcles have no reſtitutive motion, but what they derive from the Action of their *Antagoniſts* by which they are balanc'd. Thus likewiſe the *Spincters* of the *Gula*, *Anus* and *Veſica*, having no proper *Antagoniſts*, are always in a ſtate of Contraction, and ſuffer nothing

thing to paſs 'em, but what is forced thro' 'em by the contrary Action of ſome ſtronger Muſcles, which, tho' not properly to be called *Antagoniſts*, yet on all neceſſary Occaſions perform the Office of ſuch.

That the Heart is a Muſcle, furniſh'd and inſtructed for motion like other Muſcles, is (in my Opinion at leaſt) demonſtrated beyond contradiction by Dr. *Lower* and others. And, as it is a *Solitary* Muſcle without any proper *Antagoniſt*, and not directly under the power of the Will, nor exerciſing *Voluntary* motion, it approaches neareſt to the *Sphincter* kind, which only has theſe Conditions in common with it. But in conſtant and regular Alternations of Contraction and Dilation, it differs exceedingly from all the Muſcles of the Body.

This *reciprocal Æſtus* of the Heart has given the Learned abundance of trouble; who, finding nothing peculiar in the Structure, which ſhou'd neceſſarily occaſion it, nor any *Antagoniſt*, whoſe re-action ſhould produce it, have been extreamly perplext to find out the cauſe of it.

But paſſing over the various Opinions of Authors, to avoid being tedious, I ſhall take notice here only of the very Learned Dr. *Lower*'s, in whoſe Account of the *Syſtole*, however ſolid and ingenious, I obſerve ſomething deficient, and whoſe *Hypotheſis* of the *Diaſtole* I think to be precarious and falſe.

This excellent Author, having by ſound Arguments drawn from the Structure and Mechaniſm of the Heart, eſtabliſht the Certainty of its *Muſcular Motion*, reſts ſatisfied, without taking notice of any Aſſiſtance, that the Heart receives from any other Part, except from the Brain, by the means of the eighth pair of Nerves.

Part. 2*d.* *Prop.* 67. *Prop.* 73.

The Accurate *Borellus*,in his *Oeconomia Animalis*, computes the *Motive* Power of the *Machine* of the Heart to be equal to,or to ſurmount that of a Weight of 3000 *l.* The *Obſtacles* to the motion of the Blood thro' the *Arteries* he eſteems equivalent to 180,000 *l.* which is 60 times as much as he rates the Force of the Heart at. Then deducting 45,000 *l.* for the adventitious Help of the *Muſcular Elaſtick Coat* of the *Arteries*, he leaves the Heart with a Force of 3,000 *l.* to overcome a reſiſtance of 135,000 *l.* that is, with 1 to remove 45.

Prop. 76.

This ſtupendous Effect he contents himſelf to aſcribe to the *Energy* of *Percuſſion*. But, had he proceeded in his Calculation to the Veins, which he allows to contain conſtantly a quantity of Blood, quadruple to the Contents of the Arteries, and to which this *Energy* of *Percuſſion* does either not reach at all, or but very languidly, he might probably have ſeen a neceſſity for ſome other Expedient to remove ſo inſuperable a difficulty.

But not to inſiſt rigorouſly on the exactneſs of this Calculation (tho' the great Abilities of the Author in this way, and his Ingenuity and Modeſty, are a ſufficient Warrant for the accuracy of his Computations, and the fidelity of his Accounts) we may allow a much greater Deduction, than would be juſtifiable, without leſſening the difficulty. But this account I have taken notice of purely for the ſake of the Calculation, which may be of uſe in the Sequel, the account it ſelf being in other reſpects more defective than Dr. *Lower's*, to which we will return.

The Doctor, notwithſtanding his great Sagacity, appears (to me) to have overlook'd ſomething of very great moment, and importance in the explication of the Action of the Heart. For, tho' it ſhould be granted, that the *Muſcular Fibres* of the Heart acted by the Nerves, are the immediate Inſtruments of its *Conſtriction* or *Syſtole*; yet it muſt not be denied, that the *Intercoſtal* Muſcles and *Diaphragm* are of great ſervice to aid and facilitate this Contraction, by opening a Paſſage for the Blood thro' the Lungs, which denied wou'd be an invincible Obſtacle.

Neither do they promote it that way only. The manner how they farther aſſiſt the Heart in its Contraction, will appear manifeſtly, if we conſider the different Poſture, Situation, and Capacity of the Blood-Veſſels of the Lungs in the ſeveral times of *Elevation* and *Depreſſion* of the *Coſtæ*.

The *Pulmonary* Artery riſes from the *right* Ventricle of the Heart, and runs in one Trunk, 'till it comes to the *Aſpera Arteria*, where it is divided, and ſends a Branch along with each Diviſion of the *Aſperà Arteria*, according to all the minuteſt Subdiviſions, of which it is likewiſe ſubdivided, accompanying all the *Bronchi*, in their whole progreſs through the Lungs.

The *Pulmonary* Vein, which empties it ſelf into the *Left* Ventricle of the Heart, ſpreads it ſelf on the *Aſpera Arteria* and *Bronchi*, in the ſame manner that the Artery does.

The neceſſary conſequence of this Diſpoſition is, that this Artery and Vein being coextended with, and faſten'd to the *Bronchi*, muſt needs ſuffer ſuch alteration of *Superficial* Dimenſions, as the *Bronchi* do in the *Elevation* or *Depreſſion* of the *Coſtæ*.

While the Ribs are in a ſtate of *Depreſſion* (whether before Commerce with the external Air or after) the *Annular Cartilages* of the *Bronchi* ſhrink one into another, and by that means their *Dimenſions* are exceedingly contracted. In conformity to this condition of the *Bronchi*, the *Pulmonary* Artery and Vein muſt likewiſe, either by means of their *Muſcular* Coats contract themſelves to the ſame *Dimenſions*, or lye in *Folds* or *Corrugations*, which is leſs probable.

On the other hand, when the Ribs are elevated, and the *Diaphragm* bears downward, the Air ruſhing into the Lungs, ſhoots out the *Cartilaginous* Rings, and *divaricates* the Branches of the *Trachea*, and by them extends and divaricates the ſeveral Diviſions of the *Pulmonary* Artery and Veins, and thereby lengthens and enlarges their Cavities.

This enlargement of their Cavities is very conſiderable, not only upon the ſcore of the addition, which they receive in length thereby, but alſo upon the account of their *Divarication*. For whereas, when the Ribs are depreſt, and the Lungs ſubſide, the Blood-Veſſels are not only contracted, (as I have already obſerv'd) but their Branches, which are exceeding numerous, approach one another, and lie in juxta-poſition, by which their Cavities are very much compreſs'd and ſtreightned: When the Ribs are elevated, and the Lungs turgid with Air, not only the Fibres, by which their Coats in the oppoſite ſtate were contracted, are extended; but thoſe innumerable Veſſels, which lying before in lines almoſt parallel upon one another, compreſs'd one another, making an *acute* Angle at their Junctures, are divaricated and ſeparated from each other, and make an *obtuſe*, whereby their Chanels are widen'd.

Thus a paſſage is open'd to the Blood, from the *Right* Ventricle of the Heart to the *Left*, thro' the Lungs, to which it cou'd not otherwiſe paſs; and the oppoſition, which the Blood contain'd in that Ventricle, muſt otherwiſe neceſſarily have made to its Conſtriction, is taken off, and the *Syſtole* thereby facilitated.

Nor is that all. For the *Diaſtole* being caus'd (as I ſhall in the Sequel ſhew) by the force of the Blood ruſhing into the Ventricles, this Ampliation aad Extenſion of the *Pulmonary* Artery is a ſort of *Check* or *Counterpoiſe* to it, and prevents an endeavour towards two contrary Actions at once, which muſt neceſſarily fruſtrate both. For the Heart being a *Springy*, *Compreſſible* Body, whoſe proper Action, which is Contraction, depends on the influx of certain Fluids into its Fibres, or Subſtance; and containing beſides a Fluid in its *Ventricles*, or great Cavities, in one of which is the Mouth of this Artery, the action of this Veſſel muſt in great meaſure reſemble that of a *Syringe*, whoſe extremity is immers'd in Water, the Enlargement or Expanſion of the Chanels of the Artery anſwering the drawing of the *Embolum*, as the conſtrictive motion of the Muſcle of the Heart does the preſſure of the *Atmoſphere* upon the *Surface* of the Water, the one making way for the fluid, and the other forcing it to follow, where the reſiſtance is leaſt. In this ſenſe we may allow a ſort of Attraction to the *Pulmonary*-Artery, depending wholly upon the Action of the *Intercoſtal* Muſcles and *Diaphragm*, which we muſt therefore confeſs to be very ſerviceable and inſtrumental in promoting the *Syſtole* of the Heart.

But if the Learned Author be deficient in his account of the *Syſtole*; that is, if he has not obſerv'd all the Mechaniſm and Contrivance of Nature for the Contraction of the Heart; much leſs ſufficiently has he accounted for the *Diaſtole*, or Dilatation of it, which he aſcribes to a motion of *Reſtitution* of the over-ſtrain'd Fibres, which yet he confeſſes are made for *Conſtriction* only. 'Tis true, he immediately after joins the *Influx* of the *Blood* as a concurrent cauſe; but from the ſlight notice that he takes of it, 'tis plain, that he did not ſo much as dream of any great ſhare it had in that action. His words are theſe:

Quin & (ut obiter hoc moneam) cum omnis motus contractione perficiatur, & Cordis Fibræ ad conſtrictionem ſolum factæ ſint, apparet quoque Cordis motum totum *in* Syſtole *poſitum eſſe; cumq; Fibræ ultra tonum ſuum in omni conſtrictione ejus tendantur, idcirco ubi nixus iſte abſolvitur, motu quaſi* reſtitutionis *Cor iterum relaxatur, & ſan-*

De Corde, Pag. 75.

guine a Venis influente *rurſus diſtenditur*; *a* nullo *enim cordis motu*, *niſi* tenſionem ſuam remittente, *&* *ab* irruente *ſanguine* Diaſtole *ejus libratis adeo viribus ſuccedit.*

I have tranſcribed the intire Paragraph, becauſe it contains his whole *Hypotheſis* of the *Diaſtole*, and all the notice that he takes of it thro' his whole Work. But how ſlender ſoever this may prove, it is the moſt ſubſtantial that I have any where met with, except a late one of Mr. *Cowper*, which is properly an Improvement of this, and ſhall be conſidered in the Sequel.

But, if Contraction be the ſole Action of theſe Fibres (as this Great Man confeſſes it to be) and as indeed it is of all *Muſcular* Fibres, I wonder how ſo judicious a Writer came to ſlip into ſuch an abſurdity, as to call their Diſtention (vulgarly but improperly called Relaxation) a Motion of *Reſtitution.* For from the Nature of thoſe Fibres, and their diſpoſition in the Structure of the Heart, the natural State of the Heart appears manifeſtly to be *Tonical*, and its Dilatation a State of Violence; and conſequently, the Conſtriction is the *true* motion of *Reſtitution*, and the State to which it will *ſpontaneouſly* return, when the Force is taken off, which is the work of the *Intercoſtal* Muſcles and *Diaphragm.*

Thus we are left ſtill to ſeek for the true cauſe of the *Diaſtole*, which ſeems to me to be the main and moſt difficult *Phænomenon*, relating to the Heart and the Circulation of the Blood. But in Mr. *Cowper*'s ingenious *Introduction* to his *Anatomy of Humane Bodies*, I

find

find the Share which Dr. *Lower* hints the Blood to have in that Action, further proſecuted, and improv'd into the main Inſtrument of the Dilatation of the Heart, wherein I agree intirely with him. But as to the manner, and reaſons of its being ſo very inſtrumental, I can't be ſo perfectly of his mind.

The Heart (ſays this accurate Anatomiſt) *of an Animal bears a great Analogy to the Pendulums of thoſe Artificial Automata, Clocks and Watches, whilſt its motion is performed like that of other Muſcles, the Blood doing the Office of a* Pondus.

This Explication, being but a Simile without a diſtinct application to Particulars, is beſide ſo very ſhort, that I can at beſt but give a conjecture at the meaning, which if I miſtake, I ſhall deſerve to be excuſed, and expect to be better inform'd.

By the *Blood*'s doing the Office of a *Pondus*, I ſuppoſe he means, that the Blood contributes in the ſame manner to the motion of the Heart, as the *Weights* do to that of the *Pendulum* of a *Clock*. If ſo, the Blood, according to him, muſt be the Inſtrument of *Conſtriction*; and *Dilatation* maſt be the *Natural* State, or *Spontaneous* Motion, to which it wou'd, when under no violence, return; the contrary of which, I preſume, will appear ere I have done.

But if he means, that the *Blood* in its reflux, by *gravitating* on the *Auricles* and *Ventricles*, dilates and expands 'em, acting therein as a *Counterpoiſe* to its contractions as a Muſcle, I cou'd wiſh his Deſign had not bound him up to ſo narrow a compaſs, and that he had given us an explication at large of ſo abſtruſe and ſo important a *Phænomonon* : Becauſe the *Specifick Gravity* of the Blood ſeems to me a cauſe by no means alone adequate to the effect, which it is here ſuppos'd to produce.

For, if the Blood acts only as a *weight* by meer *gravitation*, then that part of it only which deſcends from the Parts above the Heart can be employ'd in that Action. This at the largeſt computation can't amount to Five pound weight, and muſt, according to the computation of *Borellus*, force a Machine, that is able to overcome a reſiſtance of 135,000 *l.* I leave every man to deduct what he ſhall upon examination find reaſonably to be deducted, and yet ſhall reſt ſecure, that it is not to be effected in the leaſt with ſo ſmall a Weight.

But neither does the *Refluent* Blood gravitate in any ſuch proportion, as I have here aſſign'd. For to make a true eſtimate of its *Gravitation*, we muſt conſider the Circumſtances of the Liquor ſuppos'd to gravitate; in which it very much reſembles Water inclos'd in a recurve Tube, of which, if the length of the two Legs be equal, it may be ſuſpended in the Air full of Water, with the Extremities downwards, without loſing a drop, altho' the *Diameter* of thoſe Legs ſhou'd be very unequal. The Caſe of the Arteries and Veins is pretty near a parallel to a Tube, ſo fill'd and inverted. For, if the Arteries and Veins be continued Tubes, (as by the Microſcope they are made to appear) then ſuppoſing their contents to have no other determination of motion, than their own weight wou'd give them, the contain'd Fluids muſt be counterpoiſes to each other. For the Veins and Arteries being join'd at the ſmaller Extremeties, and the larger of both terminating in the ſame parallel Line, it is impoſſible, according to the Laws of *Hydroſtaticks*, that the contents of either ſhou'd overbalance t'other. How far then muſt it fall ſhort of forcing the natural Power and Reſiſtance of ſo ſtrong a Muſcle as the Heart, by meer Gravitation.

The Blood indeed has a *Progreſſive* Motion thro' its Veſſels, wherein it differs from Water, in a recurve Tube, in the Experiment above-ſtated. But, if the natural Gravitation of the Blood contributes nothing to the Dilatation of the Heart, this progreſſive motion will not be found much more ſufficient. For, as this motion is deriv'd intirely from the Heart's Conſtriction (as all accounts hitherto derive it) cou'd the Blood be ſuppos'd to re-act upon the Heart, with all the force firſt impreſs'd upon it by the Heart, it wou'd be inſufficient, unleſs we will ſuppoſe the *Force communicated* to be ſuperiour to the *Power Communicant*, which is abſurd.

But when the juſt and neceſſary Deductions for the Impediments, which the Blood meets with in its Progreſs thro' the Veſſels ſhall be made, the remaining Force will be found ſo in exceeding weak, that to prop the Blood thro' the Veins may be a task alone too great for ſo ſmall a Power, without charging it with the additional difficulty of forcing the Muſcle of the Heart.

Alphonſus Borellus, after a great deal of ſolemn pains taken to ſhew his care and exactneſs, and to poſſeſs his Reader of the truth of his Calculations, caſts up the force of the Heart, and the *Muſcular* Coat of the Arteries, to be together equal to a weight of 3,750 *l.* and allots 'em a Reſiſtance equal to 180,000 *l.* to overcome which is 45 to 1. To make up for a diſproportion, by his own confeſſion, incredible to thoſe who have not conſidered the matter as he had done, he flings into the Scale the additional *Force of Percuſſion*, which he leaves *indefinite*, and thinks ſufficient to *force any quieſcent finite Reſiſtance whatſoever.*

But as this Account and *Hypotheſis* are part of a Poſthumous Work (if a liberty of Conjecture may be allow'd in ſo uncertain a matter,) I ſhou'd ſuſpect, that theſe Papers were left unfiniſh'd by *Borellus*; or at leaſt, that in many places the laſt hand was never put to 'em. For neither in this Place, nor any other of this Work, does he account for any more than the *Syſtole* of the Heart, and the reſiſtance which is made to the progreſſive motion of the Blood in the Arteries only. This alone he found to exceed the Power of the Heart ſo prodigiouſly, that he ſeems to ſhuffle it off his Hands with a general and precarious Solution, as a difficulty that he was deſirous to be rid of. For, having aſcrib'd this *ſtupendous* (as he himſelf calls it) effect to the *Energy of Percuſſion*, he takes no care to ſatiſie his Reader any farther about it, or to refer him, or give him the expectation of ſatisfaction any where elſe; altho' he has an expreſs Treatiſe on the *Force of Percuſſion*, which was written preparatory to this, and to which he frequently refers in other Places of this Work. But what confirms my ſuſpicion, that this part was intended for a farther Reviſe by the Author, is, that he has left the Progreſs of the Blood thro' the Veins, and the *Diaſtole* of the Heart, abſolutely untouch'd, tho' they are difficulties of a much greater magnitude than this, which he has attempted to account ſo ſlightly for: For, in theſe he is excluded the benefit of *Percuſſion*, and has yet a greater reſiſtance to overcome without it. Omiſſions of this kind are ſo unuſual with this Author, where-ever he knows himſelf to go upon ſure grounds, that it is to me an Argument, that he doubted the ſufficience of his *Percuſſion*, and reſerv'd theſe important *Phænomena* for farther conſideration, without plunging himſelf into ſuch an Abſurdity, as to aſcribe to *Percuſſion* any ſuch *Energy* as to be able (ſo broken as it returns to the Heart) by its re-action to force that Power, from whence only it was at firſt deriv'd.

Dr. *Lower*, and Mr. *Cowper*, deliver their Opinions of the Cauſe of the Dilatation of the Heart ſo very ſhort, and without any Arguments to ſupport 'em, that by expoſing 'em naked, they ſeem rather to diſcourſe of it tranſiently, as men obliged by the nature of their Subjects to ſay ſomething of it, than ſolicitous to give any full or ſatisfactory Account; and therefore I ſhall proceed no farther upon 'em here.

But tho' the *Hypotheſis* of *Borellus* may, in this caſe, be found precarious or inſufficient (a misfortune that has befallen him in divers other Particulars) his *Theory* holds ſtill good. At leaſt it ought to be allowed, in juſtice to his great Abilities and Exactneſs, 'till ſome body convicts him of ſome material Error in his Calculations, which has not as yet been done by any body, that I know of.

Suppoſing then the force of the Heart, and of the *Muſcular* Coat of the Arteries, as likewiſe of the reſiſtance, which they muſt overcome, to be computed with any degree of accuracy, there remains yet ſuch a prodigious diſproportion to be accounted for, as requires ſome more powerful Agent, than any yet aſſign'd, to make up the deficiency.

What aſſiſtance the Heart receives from the action of the *Thorax* towards the facilitating its contraction, without which aſſiſtance there cou'd have been no *Syſtole*, has been already ſhewn. But neither the *Intercoſtal* Muſcles, or *Diaphragm*, which are ſo inſtrumental in that part of its action, can contribute any thing to the *Diaſtole*; becauſe they ſerve only to enlarge the cavity of the *Thorax*, and thereby to open a paſſage to the Blood from the Heart, and promote its Conſtriction.

Whatever therefore the force is, that dilates the Heart, and is the cauſe of the *Diaſtole*, it muſt be equal to that of the Heart, the *Intercoſtal* Muſcles and *Diaphragm*; to all which it acts as an Antagoniſt. I take no notice of the *Serratus Major Anticus*, and other Muſcles; which have an obſcure ſhare in the *Elevation* of the *Coſtæ*, becauſe as much may reaſonably be deducted upon the account of the *Obliquus externus Abdominis*, and other Muſcles; which having their Inſertions on ſome of the lower *Ribs*, are as inſtrumental towards the *Depreſſion* of 'em, and ſo balance the Account. But the chief uſe of theſe is in violent Reſpiration: In ordinary Reſpiration their ſhare is ſmall.

Such a real Power (which may in the leaſt be ſuſpected of any ſhare in this Action) is hard, perhaps impoſſible to be found in the *Machine* of any *Animal* Body; and yet without ſome ſuch Antagoniſt, it is as impoſſible the Circulation of the Blood ſhou'd be maintain'd. All the Engines yet diſcover'd within the Body, conſpire towards the *Conſtriction* of the Heart, which is the *State* of *Quieſcence*, to which it naturally tends. Yet we find it alternately in a *State* of *Violence*, that is, of *Dilatation*; and this upon neceſſity, becauſe upon this *Alternation* depends all Animal Life.

Some ſufficient Cauſe external muſt therefore be found, to produce this great *Phænomenon*; which Cauſe muſt be either in the *Air*, or *Atmoſphere*, becauſe we have no conſtant and immediate Commerce with any other *Mediums*.

Some great Phyſicians obſerving this, and that depriv'd by whatſoever means of Communication with the *external* Air, we became inſtantly extinct, have imagin'd, that in the Act of Inſpiration certain purer parts of the Air mixed with the Blood in the Lungs, and was convey'd with it to the Heart, where it nouriſh'd a ſort of *Vital Flame*, which was the cauſe of this reciprocal *Æſtus* of the Heart. Others not quite ſo groſs, rejecting an *Actual Flame*, have fancied that theſe fine Parts of Air mixing with the Blood in the Ventricles of the Heart, produc'd an *Efferveſcence* which dilated it. But theſe Fancies have been long ſince exploded and condemn'd upon ample Conviction; and 'tis a Point yet undetermin'd, whether any Air does mix with the Blood at all in the Lungs, or not.

But ſuppoſing, that ſome Air may inſinuate it ſelf into the *Pulmonary* Vein, it can no other way dilate the Heart than by an Effervеſcence in the Left Ventricle, which wou'd not dilate the Right. But this Opinion is contradicted by *Autopſie*, and too laboriouſly confuted by others, to be brought upon the Stage again here.

There remains therefore only the *groſs Body* of the *Atmoſphere* to be conſidered, which is undoubtedly the *true Antagoniſt* to all thoſe Muſcles, which ſerve for ordinary Inſpiration, and the Conſtriction of the Heart. This will appear more evidently, if we conſider not only the power, but the neceſſity of its Action upon *Animal* Bodies, as well as the want of other ſufficient Agents.

The Heart is a *Solitary* Muſcle of very great ſtrength, and the *Intercoſtal* Muſcles and Diaphragm, which likewiſe have no *Antagoniſts*, are a vaſt additional Force, which muſt be balanc'd by the contrary Action of ſome equivalent Power or other. For, tho' the Action of the *Intercoſtal* Muſcles be voluntary, that does not exempt 'em from the condition of all other Muſcles ſerving for *voluntary* motion, which wou'd be in a State of perpetual Contraction, notwithſtanding any Influence of the Will, were it not for the libration of *Antagoniſt* Muſcles. This libration between other Muſcles, is anſwer'd by the *Weight* of the incumbent *Atmoſphere*, which preſſes upon the *Thorax* and other parts of the Body. And, as in all other voluntary motions the influence of the Will only gives a prevalence to one of it two Powers before equilibrated, ſo here it ſerves to enable thoſe Muſcles to lift up a weight too ponderous for their ſtrength not ſo aſſiſted; and therefore as ſoon as that aſſiſtance is withdrawn, the *Coſtæ* are again depreſs'd by the meer *Gravitation* of the *Atmoſphere*, which wou'd otherwiſe remain elevated thro' the natural Tendency of thoſe Muſcles to contraction.

This is evidently prov'd from the *Torricellian* Experiments, and thoſe made upon Animals in Mr. *Boyle*'s Engine; where, as ſoon as the Air is withdrawn, and the *preſſure* thereby taken off, the Intercoſtal Muſcles and Diaphragm are contracted, and the Ribs elevated in an inſtant, and can't by any power of the Will be made to ſubſide, 'till the Air is again let in to bear 'em forcibly down.

It were ſcarce worth while to take notice here of a Miſtake of the Learned Dr. *Willis*, were it not for the great Authority of the Man, which is almoſt ſufficient to keep Error in countenace. The Doctor having obſerv'd, that the Fibres of the *External* and *Internal Intercoſtal* Muſcles ran in a contrary order, as it were, decuſſating each other, takes occaſion from thence to fanſie, that there was an oppoſition in their Office; and that as the *External* ſerv'd to raiſe up the Ribs, the *Internal* drew 'em down again, forgetting at that time, That, when a contractile Body is faſten'd at the ſeveral ends to Points unequally moveable, let the Contraction happen in what part or manner ſoever

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ver, the more moveable Point muſt be drawn towards the leſs moveable: By which Rule, whether *External* or *Internal Intercoſtals* be contracted, the lower Ribs will be forc'd to approach the upper, that is, be rais'd up.

As in the Elevation of the *Coſtæ*, the Blood, by the paſſage that is open'd for it, is in a manner ſolicited into the Lungs,; ſo in the Depreſſion of 'em, by the ſubſidence of the Lungs, and the contraction of the Blood-Veſſels, both which are conſequent thereof, the Blood is forcibly driven, as it were with an *Embolum*, thro' the Pulmonary Vein into the Left Ventricle of the Heart. And this, together with the *general Compreſſion* of the *Body* by the *weight* of the *Atmoſphere*, which ſurrounds and preſſes upon the whole Surface of it, is that Power which cauſes the Blood to mount in the Veins, after the force impreſs'd upon it by the Heart is broken and ſpent, and which is ſufficient to force the Heart from its natural State to Dilatation.

He that is able to compute the weight of a Column of Air, equal to the Surface of the whole Body, will readily grant it a power ſufficient for the Effects, which are here aſcrib'd to it. And when he conſiders, that the Bodies of Animals are compreſſible Machines, he will find that it muſt of neceſſity affect them in the manner here laid down. But tho' our Bodies be entirely compos'd of *Tubuli*, or Veſſels fill'd with Fluids; yet this preſſure, how great ſoever, being equal, cou'd have no effect upon 'em, if the ſuperficial Dimenſions were not eaſily variable; becauſe being compreſs'd on all parts with the ſame degree of Force, the contain'd Fluids cou'd not any where begin to recede, and make way for the reſt to follow, but wou'd remain as fix'd and immoveable as if they were actually ſolid. But by the Dilatation of the *Thorax*, room is made for the Fluids to move, and by the Coarctation of it freſh motion is impreſt, which is the main Spring whereby the Circulation is ſet and kept going.

This reciprocal Dilatation and Contraction of the ſuperficial Dimenſions of the Body, ſeems ſo neceſſary to Animal Life, that there is not any Animal ſo imperfect as to want it, at leaſt none to the inward Structure, of which our Anatomical Diſcoveries have yet reach'd. For, tho' moſt kinds of *Fiſh* and *Inſects*, wants both *moveable* Ribs and Lungs, and conſequently have no dilatable *Thorax*, yet that want is made up to 'em by an *Analogous* Mechaniſm, anſwering ſufficiently the Neceſſities of their Life.

Thoſe Fiſhes which have no Lungs, have *Gills*, which do the *Office* of Lungs, receiving and expelling alternately the Water, whereby the *Blood-Veſſels* ſuffer the ſame alteration of Dimenſions, that they do in the Lungs of more perfect Animals.

The Lungs or *Air-Veſſels* of Inſects, are yet exceedingly more different in Structure, Diſtribution, and Situation from thoſe of perfect Animals, than thoſe of Fiſhes are, and yet in their Uſe and Action agree perfectly with both; that is, *receiving* and *expelling* the Air, and *varying* the *Dimenſions* and *Capacities* of the *Blood-Veſſels*. Theſe having no *Thorax*, or ſeparate Cavity for the Heart and Air-Veſſels, have the latter diſtributed thro' the whole Trunk of their Bodies, by which they communicate with the *External* Air through ſeveral *Spiracula* or *Vent-holes*, to which are faſten'd ſo many little *Trachea*, or Wind-pipes, which thence ſend their Branches to all the Muſcles and *Viſcera*, and ſeem to accompany the Blood-Veſſels all over the Body, as they do in the Lungs only of perfect Animals. By this diſpoſition in every *Inſpiration*, the whole Body of theſe little Animals is inflated, and in every *Expiration* compreſs'd; and conſequently the Blood-Veſſels muſt ſuffer a *Viciſſitude* of Extenſion and Contraction, and a greater motion muſt thereby be impreſs'd upon the Fluids contain'd in 'em, than the Heart, which does not in thoſe Creatures appear to be Muſcular, ſeems capable of giving.

The only Animal that is exempted from this neceſſary condition of *Breathing*, or *receiving* and *expelling alternately ſome Fluid* into and out of the Body, is a *Fœtus*. But this, while included in the Womb, has little more than a *vegetative* Life, and ought ſcarce to be reckon'd among the number of *Animals*. For, were it not for that ſmall ſhare of *Muſcular* Motion, which it exerciſes in the Womb, it might without abſurdity be accounted for as a Graft upon, or Branch of the Mother.

Concerning the immediate matter, and means of Life, and Nutrition, Authors are not agreed, nor is it the buſineſs of this place to reconcile, or decide their differences, but to account for the motion of the Blood thro' the Veſſels only. In order to this, it will be neceſſary to obſerve, that the Pulſation of the Heart in a *Fœtus* is ſo very weak and obſcure, and the motion of the Blood ſo extream ſlow and languid, as to be ſcarce, if at all, perceivable, as has been experienced in the Diſſection of Puppies before Reſpiration had. To produce ſuch a feeble Palpitation, and creeping Motion, no greater force ſeems to be required, than may be deriv'd from the Communication between the Veſſels of the Mother and *Fœtus* in the *Placenta.* I am not ignorant, that divers very Learned Anatomiſts (whom the Crowd have implicitly follow'd) have abſolutely rejected all Communication between theſe Veſſels. But, with ſubmiſſion to Great Authorities, I think they have acted arbitrarily, and without ſufficient Warrant from Reaſon or Experiment: For neither are the Arguments which they bring againſt it concluſive, nor the Office which they aſſign to the Umbilical Veſſels in lieu of it, proper, or natural to thoſe Veſſels, or the reality of the Fact made out by any ſubſtantial Reaſons. Thoſe that reject this Communication uſually do it in favour of one or both of theſe Opinions, that the Arteries of the *Uterus* do depoſite a Nutritive Juice, or a Juice impregnate *with Air* in the *Placenta*, which is ſuck'd in by the *Umbilical* Vein, and convey'd to the *Fœtus*, for the neceſſary Uſes of Nutrition and Life. Now thoſe that patronize either of theſe Opinions, lead Nature an unneceſſary Dance. For if the *Maternal* Blood does really contain any ſuch *Nutritious*, or any ſuch neceſſary *Aerial Particles*, why ſhou'd they be ſeparated and extravaſated, to be with difficulty receiv'd into the *Umbilical* Vein, and a-

Boyle *of the Elaſticity of Air.* *Pechlinus de Aeris & alimenti defectu.*

gain mixt with the Blood, when they might more eaſily have been imparted by the plain ſimple way of Transfuſion from the Arteries of the *Mother* to the Veins of the *Fœtus*. And, that this is the courſe which Nature takes in this caſe, I am perſwaded from the eaſineſs and ſimplicity of the Method, which readily performs what might be perhaps in vain expected from t'other, and wou'd over and above find 'em, what they ſeem to grope ſo blindly about for, a firſt Mover of the Blood in a *Fœtus*.

Thoſe that contend for the conveyance of the *Nutricious* Juice, thro' the *Umbilical* Vein from the *Placenta*, are forced upon two difficulties next to Abſurdities. For firſt, they are oblig'd to make this Vein, which, as all other Veins, ſeems dedicated to the re-conveyance of Blood only, the proper and immediate Chanel, thro' which a very different Liquor is to be carried; and next, to give a Power of Attraction or Suction to it; becauſe the *Nutricious* Juice, which it is thus deſtin'd to carry, is both viſcous and ſtagnant, and has neither force to drive, nor ſubtilty to penetrate, or inſinuate it ſelf into the Capillary Veins; and therefore muſt be drawn or ſuckt as *Milk* is from the *Breaſt*, to which the *Placenta* and its *Nutricious* Juice are by the Favourers of 'em expreſly compared. But if this were the ſole uſe of the *Placenta*, and *Umbilical Veſſels*, why were the Umbilical *Arteries* ſent along with the Vein? Their buſineſs is not to bring any thing back to the *Fœtus*, nor can they contribute any thing to the benefit of the *Mother*; for the *Uterine* Arteries bring all to the *Placenta*, the Umbilical Vein carries it to the *Fœtus*, and the *Uterine* Veins convey back again the Surcharge of the *Mother's* Blood; the Umbilical *Arteries* only, have nothing to do, and are ſuperfluous and impertinent, which is contrary to the conſtant practice of Nature. Yet if *Autopſie* did in the leaſt countenance this Hypotheſis, ſome defence might ſtill be made; but we find in the Umbilical *Vein* of a *Fœtus* nothing but *Florid* Blood, ſuch as in all probability it received immediately from the *Arteries* of the *Mother* without any mixture. And therefore I can't help concluding, that this Opinion engages its Favourers in ſome Abſurdity, without Neceſſity and without Proof.

They that from the *Placenta* ſupply the Body of the *Fœtus* with *Air*, are as much diſtreſs'd as t'other; for they are forc'd to beg the Queſtion twice, which, even when granted, will not anſwer their ends. Firſt, they ſuppoſe, that an intimate mixture or confuſion of *Air* with the *Blood*, is neceſſary for the ſupport of Animal Life, a *Poſtulatum*, which perhaps the former part of this Diſcourſe may have render'd unneceſſary; and next that, the *Fœtus* is ſupply'd with *Air* from, and its *Blood* mixt with it in the *Placenta*.

But here again they fetch a Compaſs without neceſſity or proof. For if a mixture of *Air* were neceſſary to a *Fœtus*, why ſhould it be ſeparated from the *Mother's* Blood, and not rather both communicated together, ſince it is ſo much more eaſie and commodious. But neither does the *Placenta* ſeem to be inſtructed and provided for the ſeparation of *Air*, but of a much *groſſer Fluid*, deſtin'd to ſome other uſe, which *Autopſie* confirms: Yet, were both theſe Opinions true, they are however defective, and the Circular Motion of the Blood unprovided for.

By the way of *Transfuſion*, this great Phænomenon is naturally accounted for, and the ends, for which the other two Hypotheſes were divis'd, might both be anſwered with more eaſe. For the *Hyſterick* Arteries tranſmitting their Blood immediately to the *Umbilical* Vein, may very eaſily tranſmit ſuch *Nutricious* Juices or *Aerial* Particles, as are contain'd in the Blood along with it, without depoſiting 'em by the way. By this means ſo much of the Impulſe of the Mother's Blood is preſerv'd, as ſuffices to maintain that languid Circulation which a *Fœtus* enjoys. For the Blood being driven thro' the *Arteries* of the *Uterus* into the *Umbilical Vein*, is convey'd directly to the *Sinus* of the *Porta*, and thence by a ſhort and direct paſſage thro' the *Cava* to the Heart; where paſſing thro' the *Foramen Ovale* to the *Left* Ventricle, and thro' the *Canalis Arterioſus* from the *Right* and *Pulmonary* Artery, it is all deliver'd without coming at the *Lungs* to the *Aorta*, and from thence again by the *Umbilical Arteries* to the *Veins* of the *Uterus*, making a ſort of *Epicycle* to the main Circulation in the Mother.

As this Opinion is favour'd by the ſtructure and diſpoſition of the Blood-Veſſels on both parts, ſo there is nothing in it difficult to be conceiv'd, or repugnant to experience. Late Diſcoveries have made it appear, that the Arteries and Veins are continued Tubes, and that the latter contain nothing but what they receive from the former, and no reaſon appears why we ſhou'd think this Method to be varied in the *Placenta.* On the other hand, if the Arteries of the *Uterus* were continued to the Veins of the *ſame* part, and thoſe of the *Fœtus* in like manner, without communicating with each other, their confluence in the *Placenta* ſeems to be altogether impertinent, and of no uſe, and the *Umbilical* Arteries and Vein fram'd for no other ſervice or purpoſe, than to give the Blood room for an idle Sally.

Thus the reaſonableneſs of this old Opinion may be vindicated, but the certainty of it reſts upon ſtronger proof. Mr. *Cowper*, to whoſe happy Induſtry we owe the Confirmation of many ancient Diſcoveries, and the benefit of ſome new ones, has the honour to re-eſtabliſh this old, but long exploded Truth. For by pouring *Mercury* into a Branch of the *Uterine Artery* of a *Cow*, that went into one of the *Cotyledones* of the *Uterus*, he fill'd thoſe Branches of the *Umbilical* Veins, which went from that *Cotyledon* to the *Navel* of the *Fœtus*; which, with a part of the *Uterus*, he keeps prepared by him.

It wou'd be a weak Objection, to alledge, that the Obſervation and Experiment being made on the *Uterus* of a *Cow*, the Inference wou'd not hold from thence to a *Woman*, the one being *Glanduliferous*, and the other *Placentiferous*; ſince ev'ry one of theſe *Cotyledones*, or *Uterine Glandules*, is in all reſpects a little *Placenta*, and all the difference between 'em is in number, name, and magnitude. Why *Ruminants*

minants differ in this Particular from other *Viviparous* Animals, is beſide the Subject of our preſent Enquiry. But the great Flux of Blood, which conſtantly follows upon drawing the *Placenta* from Women (which is frequently ſo great as to coſt 'em their Lives) is as plain a demonſtration to Reaſon of the *Continuity* of the Veſſels, as Mr. *Cowper's* Experiment is to the Eye.

I have heard it objected by very learned Men, that if there were ſuch a *Continuity* of Veſſels, and ſuch *Transfuſion* of Blood, the *Fœtus* muſt neceſſarily periſh thro' loſs of Blood, upon the ſeparation of the *Placenta* from the *Uterus*; but that, on the contrary, no viſible flux of Blood does follow while the *Fœtus* continues wrapt in the Membrane, in which condition it may be kept alive ſome hours. To this it may be anſwer'd, that the Circulation in the *Fœtus*, being deriv'd from the Mother, may be ſuppos'd wholly to ceaſe upon the cutting off the Communication between 'em, 'till it is again renew'd more forcibly by *Reſpiration*. But if we allow the motion already impreſs'd upon the Blood to be ſufficient to keep it going a little while; yet it muſt needs be ſo exceeding languid, that the meer reſiſtance of the external Air muſt be more than enough to hinder any Efflux of Blood from a *Fœtus* before Reſpiration. How long Life may be preſerv'd without an *actual* Circulation of the Blood, is a queſtion not of this place. But we have been convinc'd by many and notorious Obſervations and Experiments, that Life has been recover'd a long time after all tokens of Reſpiration, Circulation, or even Life it ſelf have diſappear'd, ſo that we can't think the firſt Solution either impoſſible or improbable.

I expect to be told, that in the early days of *Geſtation* in *Viviparous* Animals there is no *Placenta*, or any Adheſion of the *Umbilical* Veſſels to any part of the *Mother*, and conſequently no ſuch *Transfuſion*; and that in *Oviparous* there is no *continuity*, or *communication* of Veſſels of any kind, during the whole time of *Incubation*.

But theſe Objections carry neither the weight nor difficulty along with 'em, that they may be ſuppos'd to do; for in thoſe days there is neither *Blood* nor *Blood-Veſſels*, and conſequently there can be no *Circulation* of the Blood; and the *Embryo*, of what Species ſoever, is no more than a *Vegetable* at that time; nor does the *Fœtus* of any *Viviparous* Creature enjoy any *Circulation*, or ſhew any ſigns of Animal Life, 'till after thoſe Veſſels, as well as others requiſite to the Circulation, are compleated.

It muſt be confeſs'd, that *Oviparous* Animals are denied the Benefit of this Communication; but that want is ſufficiently compenſated by a peculiar Mechaniſm, which directly anſwers the ends of *Reſpiration*, and the *preſſure* of the *Atmoſphere* upon the *Fœtus*. There is at the *obtuſe* end of an Egg a ſmall Cavity fill'd with Air, which is the ſuccedaneous Inſtrument to the *Reſpiratory* Organs. For as ſoon as the Contents begin to be warm'd by the *Incubation* of the Hen, or *any analogous* Heat of *Furnace* or *Dunghil*, the ſeveral Humors of the Egg require a *fermentative* motion,

tion, and the *Air* contain'd in the *Cavity* or *Veſicle*, at the *obtuſe* end of the Egg is rarefied, and the Veſicle extended and enlarg'd, and conſequently the other Contents are compreſt; to which the *fermentative* motion naturally reſiſts. But both Bodies being as well *compreſſible* as *dilatable*, and both having an *expanſive* motion impreſt upon 'em by *Incubation*, the compreſſion and renitency will be mutual, but varied in degree, according as either, thro' the variation of Circumſtances, ſhall prevail. By this means, an Alternation of Compreſſion and Dilatation will be produc'd in both, anſwering the *reſpiratory* motion by which a motion will be communicated, which, as ſoon as the Organs by which it ſhou'd be regulated are compleated, will in the Body of the *Pullus* be *regular* and *circulatory*.

Fabritius ab *Aquapendente*, and after him, our Great Dr. *Harvey*, have aſſign'd divers Uſes to this Cavity or Air Veſicle, the Extravagance of which have perhaps deterr'd others from enquiring ſo much into the Uſe, as the Importance of it requir'd. But tho' I can't agree to that *Perſpiration*, *Refrigeration*, and *Reſpiration*, which they make it the Inſtrument of; yet perhaps the *Air*, that was inclos'd in that *Cavity*, may thro' the augmentation of the Body of the *Pullus*, and its own *Rarefaction* (which is at laſt ſo great as to occupy half the Shell) break the *Membrane*, which ſeparted it from the *Pullus*, and thereby give ſo much *Reſpiration* as to form the *chirping Voice*, which is often heard before the breaking of the Shell, and with it give an Addition of Strength to enable it to break the Shell. But how it ſhou'd reſpire ſooner, is to me inconceivable.

There are many Problems of great ſeeming difficulty, the Solutions of which flow naturally from what has been laid down here: But intending to proſecute this Subject farther, and to treat of the Impediments of Reſpiration, and the Conſequences of Reſpiration obſtructed or intermitted, I ſhall reſerve 'em for that opportunity, and content my ſelf here to attempt the *Harveyan* Problem only, which has given abundance of Authors ſo much perplexity.

That incomparable Philoſopher enquires, *Why a* Fœtus, *taken out of the* Uterus *with the* Membranes *intire*, *ſhall live in Water ſome hours without communication with the* external Air; *whereas if it be taken out and ſuffer'd once to breath, it can't afterwards ſurvive a moment without the benefit of* Reſpiration.

Granting the Fact to be as he has deliver'd it, which yet is not ſo in all caſes, the main difficulty is grounded on a miſtake, which from the ſtating of the Queſtion I find this Great Man to have ſlipt into. For he thinks, that a *Fœtus* is ſooner ſuffocated after having once breath'd, than if it had not breath'd at all, and that by breathing it had contracted ſomething which render'd it more periſhable. *Idem tamen ſecundis exutus*, (ſays he) *ſi ſemel* aerem *intra* Pulmones *attraxerit*, *poſtea ne momentum quidem temporis abſq; eo durare poſſit*, *ſed confeſtim moriatur*. And preſently after, *Siquidem conſtat*, *fœtum*, *poſtquam* eum ſemel *hauſerit*, citius *ſuffocari*; *quam cum* *ab* illo prorſus *accebatur*. The Doctor obſerving a *Fœtus* to live longer without Reſpiration, and to diſpence better with the want of Air while included in the Membranes intire, than it cou'd afterwards; infers thence, that the Air does in the firſt Act of Inſpiration impreſs upon the Lungs ſome quality, which renders it ever after more indiſpenſably neceſſary. But allowing his Obſervation, I muſt yet deny his Inference to be good: For deprive a *Fœtus* of means of reſpiring, and then take it out of the Membranes, and it ſhall be as ſoon ſuffocated, as if it had reſpired before. This proves, that this neceſſity of intercourſe with the Air, by way of the Lungs, is not the Offspring, but the Parent of Reſpiration, and that, that Learned Man was drawn into a Fallacy of *Non cauſa pro cauſa.*

The reaſon of this Neceſſity is the preſſure of the external Air upon the Surface of the Body, from which it was defended by the interpoſition of the Membranes and the Humors contain'd, which are not ſo compreſſible as the Body of the *Fœtus* it ſelf. So ſoon therefore as the *Fœtus* is excluded, and expos'd to the immediate contact of the ambient Atmoſphere, the Veſſels and all the Cavities of the Body muſt neceſſarily be ſo compreſs'd, that the Fluids can't have room for motion, and conſequently the *Fœtus* cou'd have no Life, if Nature had not contriv'd by the motion of the *Thorax* to remove and admit that preſſure alternately, and thereby to impreſs a motion on the Fluids, which is the Spring of Life. But this motion of the *Thorax* being any way ſuppreſs'd, the equal preſſure of the Atmoſphere

ſphere on all parts occaſions a total Ceſſation of Motion, which is Death.

I ſhall proſecute this Subject no farther now, nor trouble the Reader with any Apology, for diſſenting from thoſe Great Men herein named; becauſe, I hope, I have done it with modeſty, and all the reſpect due to ſo great Authorities, and have aſſign'd nothing which is not matter of Fact uncontroverted, or deduc'd from it by plain mechanical Neceſſity.

Some

Some Thoughts and Experiments concerning Vegetation. *By* John Woodward, *M. D. of the College of Phyſicians, and R. S. and Profeſſor of Phyſick in* Greſham College.

THE *Ancients* generally intituled the *Earth* to the Production of the *Animals*, *Vegetables*, and *other Bodies* upon and about it; and that for that reaſon 'twas, that they gave it ſo frequently the Epithets of *Parent* and *Mother* *. They were of opinion, that it furniſhed forth the *Matter* whereof *thoſe Bodies* conſiſt; and received it all back again at their Diſſolution for the Compoſure of *others*. Even thoſe who aſſerted *four Elements*, ſuppoſed that the *Earth* was the *Matter* that *conſtituted* thoſe Bodies; and that *Water* and the *reſt*, ſerv'd only for the *Conveyance* and *Diſtribution* of that *Matter*, in order to the *forming* and *compoſition* of them. 'Tis true, *Thales*, a Philoſopher of the firſt rank in thoſe early Ages, has been thought to have Sentiments very different from theſe; but that without juſt Grounds, as I think I have ſufficiently proved in another Paper, which I am ready to produce.

* *Terra Parens.* Γῆ μήτηρ πάντων. *Terra Mater.*

But tho' *Antiquity* thus gave its *Vote* for *Terreſtrial Matter*, ſeveral of the *Moderns*, and ſome of very *great Name* too, both *here* and *abroad*, have gone quite counter, and given *theirs* in behalf of *Water*. The *Dignity* of the *Perſons* that have eſpouſed it, as well as their *Numbers*, renders this Doctrine very conſiderable, and well worth our enquiring into. The great Reſtorer of *Philoſophy* in this laſt Age, my Lord *Bacon*, is of opinion, *That for Nouriſhment of* Vegetables, *the Water is almoſt all in all; and that the Earth doth but keep the Plant upright, and ſave it from over-heat, and over-cold* †. Others there are who are ſtill more expreſs; and aſſert Water to be the only Principle or Ingredient of all natural things. They ſuppoſe that, by I cannot tell what Proceſs of Nature, Water is *tranſmuted* into *Stones*, into *Plants*, and, in brief, all other Subſtances whatever. *Helmont*, * particularly, and his *Followers*, are very poſitive in this; and offer ſome *Experiments* to render it credible. Nay, a very *extraordinary Perſon* of our our own *Nation* † tries thoſe *Experiments* over again; and diſcovers a great Propenſity to the ſame Thoughts and Opinion they had; declaring for this *Tranſmutation of Water* into *Plants* and *other Bodies*, tho' with great Modeſty and Deference, which was his uſual manner.

† *Nat. Hiſt. Cent.* 5. §.411.

* *Complexionum atque Miſtion. Element. Figm.*

† Mr. *Boyl*, *Scept. Chym. par.* 2.

The *Experiments* they inſiſt upon are chiefly *two*; the *firſt* is, that *Mint*, and ſeveral *other*

Plants proſper and thrive very greatly in *Water*. The *other* is this; they take a certain quantity of *Earth*, and *bake* it in an *Oven*; then they weigh it, and put it into an *Earthen Pot*. Having well water'd this *Earth*, they make choice of ſome fit *Plant*, which, being firſt carefully *weigh'*d, they *ſet* in it. There they let it grow, continuing to *water* it for ſome time, 'till 'tis much advanced in *bigneſs*: Then they take it up; and tho' the *Bulk* and *Weight* of the *Plant* be much greater than when *firſt ſet*, yet upon *baking* the *Earth*, and *weighing* it, as at firſt, they find it little or not at all diminiſhed in *weight*; and therefore conclude, 'tis not the *Earth* but *Water*, that nouriſhes and is *turn'd* into the Subſtance of the *Plant*.

I muſt confeſs I cannot ſee how *this Experiment* can ever be made with the *nicety* and *juſtneſs* that is requiſite, in order to *build* upon it ſo *much* as *theſe Gentlemen* do. 'Tis hard to weigh *Earth* in that *quantity*, or *Plants* of the *ſize* of thoſe they mention, with any great *exactneſs*; or to *bake* the Earth with that *accuracy*, as to reduce it *twice* to juſt the *ſame Drineſs*. But I may wave all this; for tho' the *Experiment* be never ſo eaſily practicable, and all the Accidents of it exactly as they ſet forth, yet nothing like what they *infer* can poſſibly be concluded from it; unleſs *Water*, which they ſo plentifully beſtow upon the *Plant* in *this Experiment*, be *pure*, *homogeneous*, and not charged with any *terreſtrial Mixture*; for if it be, the Plant after all may owe its *growth* and *increaſe* intirely to *that*.

Some *Waters* are indeed ſo very *clear* and *tranſparent*, that one would not eaſily ſuſpect any *terreſtrial Matter* were latent in them; but they may be *highly ſaturated* with ſuch *Matter*, tho' the Eye be not preſently able to deſcry or diſcern it. 'Tis true, *Earth* is an *Opake Body*; but it may be ſo far diſſolved, reduced to ſo extreme ſmall Particles, and theſe ſo *diffuſed* through the *watery Maſs*, as not ſenſibly to impede *Viſion*, or render the Water much the leſs *diaphanous*. *Silver* is an *Opake*, and indeed a very *denſe Body*; and yet, if perfectly *diſſolved* in *Sp.* of *Nitre*, or *Aqua Fortis*, that is *rectified* and thorowly *fine*, it does not *darken* the *Menſtruum*, or render it leſs *pellucid* than before *. And other Inſtances there are, that oftentimes *great quantities* of *Opake Matter* are ſuſtain'd in *Fluids*, without conſiderably ſtriking the *Eye*, or being perceived by it. So that were there *Water* any where found ſo *pure*, that the quickeſt Eye could diſcover in it no *tereſtrial Intermixture*; that would be far ſhort of a *Proof*, that in reality there was *none*.

But after all, even the *cleareſt Water* is very far from being *pure* and wholly *defecate*, in any part of the World that I can learn. For Ours here, I have had an Opportunity of examining it over a good part of *England*; and cannot ſay I ever met with any, that, however freſh and newly taken out of the Spring, did

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* *Provided the* Silver *be* pure *and abſolutely* refin'd*: For the leaſt admixture of* Copper *will produce a* blue Tincture *in the* Menſtruum; *as that of ſome* other Bodies, *one* different.

not exhibit, even to the naked Eye, great numbers of exceeding ſmall terreſtrial Particles diſſeminated through all parts of it. Thicker and craſſer Water exhibits them in ſtill greater Plenty.

Theſe are of two general kinds. The one a vegetable terreſtrial Matter, conſiſting of very different Corpuſcles; ſome whereof are proper for the formation and increment of one ſort of Plant, and ſome of another; as alſo ſome for the nouriſhment of one part of the ſame Plant, and ſome of another. The other kind of Particles ſuſtain'd in Water are of a Mineral Nature. Theſe likewiſe are of different ſorts. In ſome Springs we find Common Salt, in others *Vitriol*, in others *Alum*, *Nitre*, *Sparr*, *Ochre*, &c. nay, frequently ſeveral of theſe, or other Minerals, all in the ſame Spring; the Water as it drains and paſſes thorough the *Strata* of Stone, Earth, and the like, taking up and bearing along ſuch looſe Mineral Corpuſcles, as it meets with in the Pores and Interſtices of thoſe *Strata*, and bringing them on with it quite to the Spring. All Water whatever is much charged with the Vegetable Matter, this being fine, light, and eaſily moveable. For the Mineral, the Water of Springs contains more of it than that of Rivers, eſpecially when at diſtance from their Sources; and that of Rivers more than the Water that falls in Rain. This I have learn'd from ſeveral Trials, which I muſt not give Account of here; my Drift in this place being only to evince the Exiſtence of terreſtrial Matter in Water.

Any one who deſires farther ſatisfaction in this, may eaſily obtain it, if he only put Water into a clear Glaſs Viol, ſtopping it cloſe, to keep Duſt and other exterior Matter out, and letting it ſtand, without ſtirring it for ſome Days: He'll then find a conſiderable Quantity of terreſtrial Matter in the Water, however pure and free it might appear when firſt put into the Viol. He'll in a very ſhort time obſerve, as I have frequently done, the Corpuſcles that were at firſt, while the Water was agitated and kept in motion, ſeparate, and hardly viſible *, by degrees, as the Water permits, by its becoming more ſtill and at reſt, aſſembling and combining together; by that means forming ſomewhat larger and more conſpicuous *Moleculæ*. Afterwards he may behold theſe joining and fixing each to other, by that means forming large thin Maſſes, appearing like *Nubeculæ*, or Clouds in the Water; which grow more thick and opake, by the continual appulſe and accretion of freſh Matter. If the ſaid Matter be chiefly of the Vegetable kind, 'twill be ſuſtain'd in the Water; and diſcover at length a green Colour, becoming ſtill more and more of that Colour, I mean an higher and more ſaturate Green, as the Matter thickens and encreaſes. That this *Matter* inclines ſo much to that *Colour*, is the leſs ſtrange, ſince we ſee ſo large a ſhare of it, when conſtituting Vegetables wearing the ſame Colour in them. But if there be any conſiderable quantity of meer Mineral Matter in the Water, this, being

* *To ſay nothing of thoſe that were not diſcernible.*

of a greater ſpecifick Gravity than the Vegetable, as the Particles of it unite and combine in ſuch Number, 'till they form a *Molecula*, the Impetus of whoſe Gravity ſurpaſſes that of the Reſiſtance of the Water, ſubſides a great deal of it to the *bottom*. Nor does it only fall down it ſelf, but frequently entangling with the *Vegetable Nubeculæ*, forces them down along with it.

The Reaſon why Bodies, when diſſolved and reduced to extreme ſmall Parts, are ſuſtain'd in Liquors that are of leſs ſpecifick Gravity than thoſe Bodies are, hath been pointed at by a late ingenious Member of this Society *. He is indeed far from having adjuſted all the *Momenta* of this Affair; however it muſt be admitted, that, in the *dividing* or *ſolution* of Bodies, their Surfaces do not decreaſe in the ſame Proportion that their Bulk does. Now the Gravity of a Body, which is the Cauſe of its ſinking or tendency downwards, is commenſurate to its Bulk; but the Reſiſtance that the Liquor makes, is proportion'd, not to the Bulk, but to the extent of the Surface of the Body immerſed in it. Whence 'tis plain, a Body may be ſo far divided, that its Parts may be ſuſtain'd in a Fluid, whoſe ſpecifick Gravity is leſs than that of the ſaid Body. Nay, 'tis Matter of Fact that they frequently are ſo; and we daily ſee *Menſtrua* ſupporting the Parts of *Metals*, and other Bodies, that are of ſix, ten, nay, almoſt twenty times the Spec. Grav. of thoſe *Menſtrua*. And as the Parts of Bodies when divided, are thus ſupported in a Fluid; ſo

* Mr. *W. Molineux*, *Philoſ. Tranſ. No.* 181.

ſo when they occur and unite again, they muſt ſink of courſe, and fall to the Bottom.

Upon the whole, 'tis palpable and beyond reaſonable Conteſt, that *Water* contains in it a very conſiderable Quantity of terreſtrial Matter. Now the Queſtion is, to which of theſe, the Water, or the Earthy Matter ſuſtain'd in it, Vegetables owe their Growth and Augment: For deciding of which, I conceive the following Experiments may afford ſome Light; and I can ſafely ſay, they were made with due Care and Exactneſs.

Anno 1691.

I choſe ſeveral *Glaſs Viols*, that were all, as near as poſſible, of the ſame ſhape and bigneſs. After I had put what Water I thought fit into every one of them, and taken an Account of the weight of it, I ſtrain'd and ty'd over the Orifice of each Viol, a Piece of Parchment, having an hole in the middle of it, large enough to admit the Stem of the Plant I deſign'd to ſet in the Viol, without confining or ſtraightning it ſo as to impede its *Growth*. My Intention in this, was to prevent the incloſed Water from evaporating, or aſcending any other way than only thorough the Plant to be ſet therein. Then I made choice of ſeveral Sprigs of Mint, and other Plants, that were, as near as I could poſſibly judge, alike freſh, ſound, and lively. Having taken the weight of each, I placed it in a Viol, order'd as above; and as the Plant imbib'd and drew off the Water, I took care to add more of the ſame from time to time, keeping an Account of the weight of all I added. Each of the Glaſſes were, for better diſtinction, and the more eaſie keeping a Regiſter of all Circumſtances, noted with a different Mark or *Letter*, *A*, *B*, *C*, *&c.* and all ſet in a Row in the ſame Window, in ſuch manner that all might partake alike of *Air*, *Light*, and *Sun.* Thus they continued from *July* the Twentieth, to *October* the Fifth, which was juſt Seventy ſeven Days. Then I took them out, weigh'd the Water in each Viol, and the Plant likewiſe, adding to its weight that of all the Leaves that had fallen off during the time it ſtood thus. And Laſtly, I computed how much each Plant had gain'd ; and how much Water was ſpent upon it. The Particulars are as follows.

‘ (A.) *Common Spear-Mint*, ſet in *Spring-Water.* The Plant weighed when put in *July* 20. juſt 27 Grains ; when taken forth, *Octob.* 5. 42 Grains : So that in this ſpace of 77 Days, it had gained in weight 15 Grains.

‘ The whole Quantity of Water expended, during theſe 77 Days, amounted to 2558 Gr. Conſequently the weight of the Water taken up, was $170\frac{8}{15}$ times as much as the Plant had got in weight.

‘ (B.) *Common Spear-Mint*, *Rain-Water*. The Mint weigh'd, when put in, Gr. $28\frac{1}{4}$; when taken out Gr. $45\frac{3}{4}$, having gain'd in 77 Days Gr. $17\frac{1}{2}$.

‘The Diſpendium of the Water Gr. 3004, ‘which was $171\frac{22}{35}$ times as much as the Plant ‘had received in weight.

‘(C.) *Common Spear-mint*, *Thames-water.* The ‘Plant when put in, Gr. 28, when taken forth, ‘Gr. 54. So that in 77 Days it had gained ‘Gr. 26.

‘The Water expended, amounted to Gr. ‘2493. which was $95\frac{23}{26}$ times as much as the ‘additional weight of the Mint.

‘(D.) *Common Solanum*, or *Night-ſhade* : ‘*Spring-water.* The Plant weigh'd, when put ‘in, Gr. 49; when taken out 106, having ‘gain'd in 77 Days 57 Gr.

‘The Wat. expended during the ſaid time, ‘was 3708 Gr. which was 65,$\frac{3}{7}$ times as much ‘as the Augment of the Plant.

‘*This Specimen* had ſeveral *Buds* upon it, ‘when firſt ſet in the Water. *Theſe* in ſome ‘Days became fair *Flowers*, which were at ‘length ſucceeded by *Berries.*

‘(E.) *Lathyris ſeu Cataputia Gerh. Spring-* ‘*Water.* It weigh'd, when put in, Gr. 98. ‘when taken forth, Gr. $101\frac{1}{2}$. The additional ‘weight for this whole 77 Days, being but ‘Gr. $3\frac{1}{2}$.

‘The Quantity of Water ſpent upon it, du‘ring that time, Gr. 2501. which is $714\frac{4}{7}$ times as much as the Plant was augmented.

Several other Plants *were try'd, that did* not thrive *in* Water, *or ſucceed any better than the* Cataputia *foregoing : But*

But 'tis beſides my purpoſe to give a particular Account *of them here.*

(F, G.) *Theſe Two Viols* were fill'd, the former (F) with *Rain*, the other with *Spring-water*, at the ſame time as thoſe above-mention'd were; and ſtood as long as they did. But they had neither of them any Plant; my Deſign in theſe being only to inform my ſelf, whether any Water exhaled out of the Glaſſes, otherwiſe than *thorow* the Bodies of the Plants. The Orifices of theſe two Glaſſes were cover'd with Parchment; each piece of it being perforated with an hole of the ſame bigneſs with thoſe of the Viols above. In this I ſuſpended a bit of Stick about the thickneſs of the Stem of one of the aforeſaid Plants, but not reaching down to the Surface of the included Water. I put them in thus, that the Water in theſe might not have more Scope to evaporate than that in the other Viols. Thus they ſtood the whole 77 Days in the ſame Window with the reſt; when, upon Examination, I found none of the Water in theſe waſted or gone off. Tho' I obſerved both in theſe, and the reſt, eſpecially after hot Weather, ſmall Drops of Water, not unlike Dew, adhering to the Inſides of the Glaſſes, that Part of them, I mean, that was above the Surface of the encloſed Water.

The Water in theſe two Glaſſes that had no Plants in them, at the end of the Experiment, exhibited a larger Quantity of terreſtrial Matter than that in any of thoſe that had the Plants in them did. The Sediment at the bottom of the Viols was greater; and the

Nubeculæ diffus'd through the Body of the Water thicker. And of that which was in the others, ſome of it proceeded from certain ſmall Leaves that had fallen from that part of the Stems of the Plants that was within the Water, wherein they rotted and diſſolved. The terreſtrial Matter in the Rain-water was finer than that in the Spring-water.

Anno 1692.

The Glaſſes made uſe of in this, were of the ſame ſort with thoſe in the former Experiment; and cover'd over with Parchment in like manner. The Plants here were all *Spearmint*; the moſt kindly, freſh, ſprightly Shoots I could chuſe. The Water, and the Plants were weigh'd as above; and the Viols ſet in a Line, in a South Window; where they ſtood from *June* 2d, to *July* 28. which was juſt 56 Days.

'(H.) *Hyde-park Conduit-water*, alone. The '*Mint* weighed, when put in, 127 Gr. when 'taken out, 255 Gr. The whole Quantity of 'Water expended upon this Plant, amounted 'to 14190 Gr.

'This was all along a very kindly Plant; 'and had run up to above two Foot in height. 'It had ſhot but one conſiderable collateral 'Branch; but had ſent forth many and long 'Roots, from which ſprung very numerous, 'tho' ſmall and ſhort, leſſer Fibres. Theſe leſſer Roots came out of the larger on two oppoſite ſides, for the moſt part; ſo that each

'Root, with its *Fibrillæ*, appear'd not unlike 'a ſmall Feather. To theſe *Fibrillæ* adher'd 'pretty much terreſtrial Matter. In the Water which was at laſt thick and turbid, was a 'green Subſtance reſembling a fine thin *Conferva*.

'(I.) The *ſame Water*, alone. The *Mint* 'weigh'd, when put in, 110 Gr. when taken 'out, 249. Water expended, 13140 Gr.

'This Plant was as kindly as the former, 'but had ſhot no collateral Branches. Its 'Roots, the Water, and the green Subſtance, 'all much as in the former.

'(K.) *Hyde-Park, Conduit-water*, in which 'was diſſolved an Ounce and half of *Common* '*Garden-earth*. The *Mint* weigh'd, when put 'in, 76 Gr. when taken out 244 Gr. Water 'expended, Gr. 10731.

'This Plant, tho' it had the Misfortune to 'be annoy'd with many ſmall Inſects that happened to fix upon it; yet had ſhot very conſiderable collateral Branches; and at leaſt 'as many Roots as either that in H or I; 'which had a much greater Quantity of terreſtrial Matter adhering to the Extremities 'of them. The ſame green Subſtance here, 'that was in the two preceding.

'(L.) *Hyde-Park Water*, with the ſame Quanty of Garden-mould as in the former. The '*Mint* weigh'd, when put in, 92 Gr. when 'taken out 376 Gr. The Water expended 14950 Gr.

'This Plant was far more flouriſhing than 'any of the precedent; had ſeveral very con-

‘ ſiderable collateral Branches, and very nu-
‘ merous Roots, to which terreſtrial Matter
‘ adhered very copiouſly.

‘ The Earth in both theſe Glaſſes was ve-
‘ ry ſenſibly and conſiderably waſted, and leſs
‘ than when firſt put in. The ſame ſort of
‘ green Subſtance here as in thoſe above.

‘ (M.) *Hyde-Park Water*, diſtilled off with a
‘ gentle Still. The *Mint* weigh'd, when put in,
‘ 114 Gr. when taken out 155. The Water
‘ expended, 8803 Gr.

‘ This Plant was pretty kindly; had two
‘ ſmall collateral Branches, and ſeveral Roots,
‘ tho' not ſo many as that in H or I, but as
‘ much terreſtrial Matter adhering to them
‘ as thoſe had. The Water was pretty thick;
‘ having very numerous ſmall terreſtrial Parti-
‘ cles ſwimming in it, and ſome Sediment at
‘ the bottom of the Glaſs. This Glaſs had
‘ none of the green Matter above-mentioned,
‘ in it.

‘ (N.) The Reſidue of the Water, which re-
‘ main'd in the *Still* after that in M, was di-
‘ ſtill'd off. It was very turbid, and as high-
‘ coloured (reddiſh) as ordinary Beer. The
‘ *Mint* weigh'd, when put in, 81 Gr. when
‘ taken out, 175 Gr. Water expended, 4344
‘ Gr. This Plant was very lively; and had
‘ ſent out ſix collateral Branches, and ſeveral
Roots.

(O.) *Hyde-Park Conduit-water*, in which was
diſſolved a Drachm of Nitre. The Mint ſet
in this ſuddenly began to wither and decay;
and

and died in a few Days: As likewiſe did two more Sprigs, that were ſet in it, ſucceſſively. In another Glaſs I diſſolved an Ounce of good Garden-mould, and a Drachm of Nitre; and in a third, half an Ounce of Wood-aſhes, and a Drachm of Nitre; but the Plants in theſe ſucceeded no better than in the former. In other Glaſſes I diſſolved ſeveral other ſorts of Earths, Clays, Marles, and variety of Manures, *&c.* I ſet Mint in diſtill'd Mint-water; and other Experiments I made, of ſeveral kinds, in order to get Light and Information, what haſtened or retarded, promoted or impeded Vegetation; but theſe do not belong to the Head I am now upon.

(P.) *Hyde-Park Conduit-water.* In this I fix'd a Glaſs Tube about ten Inches long, the Bore about one ſixth of an Inch in Diameter, fill'd with very fine and white Sand, which I kept from falling down out of the Tube into the Viol, by tying a thin piece of Silk over that end of the Tube that was downwards. Upon Immerſion of the lower end of it into the Water, this by little and little aſcended quite to the upper Orifice of the Tube. And yet, in all the fifty ſix Days which it ſtood thus, a very inconſiderable Quantity of Water had gone off, *viz.* ſcarce twenty Grains; tho' the Sand continued moiſt up to the top 'till the very laſt. The Water had imparted a green Tincture to the Sand, quite to the very top of the Tube. And, in the Viol, it had precipitated a greeniſh Sediment, mix'd with black. To the bottom and ſides of the Tube, as far as 'twas immers'd in the Water, adher'd her'd pretty much of the green Subſtance deſcribed above. Other like Tubes I fill'd with Cotton, Lint, Pith of Elder, and ſeveral other porous Vegetable Subſtances; ſetting ſome of them in clear Water; others in Water tinged with Saffron, Cochinele, *&c.* And ſeveral other Trials were made, in order to give a mechanical Repreſentation of the motion and diſtribution of the Juices in Plants; and of ſome other *Phænomena* obſervable in Vegetation, which I ſhall not give the Particulars of here, as being not of uſe to my preſent deſign.

(Q, R, S,) *&c.* Several Plants ſet in Viols, ordered in like manner as thoſe above, in *October*, and the following colder months. Theſe throve not near ſo much; nor did the Water aſcend in nigh the quantity it did in the better Seaſons, in which the before recited Trials were made.

Some Reflexions upon the foregoing Experiments.

1. *In Plants of the ſame kind, the leſs they are in Bulk, the ſmaller the Quantity of the fluid Maſs, in which they are ſet, is drawn off; the Diſpendium of it, where, the Maſs is of equal thickneſs, being pretty nearly proportioned to the Bulk of the Plant.* Thus that in the Glaſs mark'd A, which weig'd only 27 Gr. drew off but 2558 Grains of the Fluid; and that in B, which weigh'd only 28¼, took up but 3004 Gr. whereas that in H, which

weigh'd 127 Grains, ſpent 14190 Gr. of the Liquid Maſs.

The Water ſeems to aſcend up the *Veſſels* of Plants, in much the ſame manner as up a Filtre; and 'tis no great wonder that a larger Filtre ſhould draw off more Water than a leſſer; or that a Plant that has more and larger Veſſels, ſhould take up a greater ſhare of the Fluid in which it is ſet, than one that has fewer and ſmaller ones can. Nor do I note this as a thing very conſiderable in it ſelf, but chiefly in regard to what I am about to offer beneath; and that it may be ſeen that, in my other Collations of Things, I made due Allowance for this Difference.

2. *The much greateſt part of the fluid Maſs, that is thus drawn off and convey'd into the Plants, does not ſettle or abide there; but paſſes through the pores of them, and exhales up into the Atmoſphere.* That the Water in theſe Experiments aſcended only through the Veſſels of the Plants, is certain. The *Glaſſes* F and G, that had no Plants in them, tho' diſpoſed of in like manner as the reſt, remain'd at the End of the Experiment, as at firſt; and none of the Water was gone off. And that the greateſt part of it flies off from the Plant into the Atmoſphere, is as certain. The leaſt Proportion of the Water expended, was to the Augment of the Plant, as 46 or 50 to 1. And in ſome the weight of the Water drawn off, was 100, 200, nay, in one above 700 times as much as the Plant had received of Addition.

This ſo continual an Emiſſion and Detachment of Water, in ſo great Plenty from the Parts of Plants, affords us a manifeſt reaſon why Countries that abound with Trees, and the larger Vegetables eſpecially, ſhould be very obnoxious to Damps, great Humidity in the Air, and more frequent Rains, than others that are more open and free. The great Moiſture in the Air, was a mighty inconvenience and annoyance to thoſe who firſt ſettled in *America*; which at that time was much overgrown with Woods and Groves. But as theſe were burnt and deſtroy'd, to make way for Habitation and Culture of the Earth, the Air mended and cleared up apace, changing into a Temper much more dry and ſerene than before.

Nor does this Humidity go off pure and alone; but uſually bears forth with it many Parts of the ſame Nature with thoſe whereof the Plant, through which it paſſes, conſiſts. The *Craſſer* indeed are not ſo eaſily born up into the Atmoſphere; but are uſually depoſited on the Surface of the Flowers, Leaves, and other Parts of the Plants: Hence comes our Manna's, our Honeys, and other Gummous Exſudations of Vegetables. But the finer and lighter Parts are with greater eaſe ſent up into the Atmoſphere. Thence they are conveyed to our Organs of Smell, by the Air we draw in Reſpiration; and are pleaſant or offenſive, beneficent or injurious to us, according to the Nature of the Plants from whence they ariſe. And ſince theſe owe their Riſe to the Water that aſcends out of the Earth through the Bodies of Plants, we cannot be far to ſeek for the Cauſe why they are more numerous in the Air, and we find a greater quantity of Odors exhaling from Vegetables, in warm, humid Seaſons, than in any other whatever.

3. *A great part of the terreſtrial Matter that is mix'd with the Water, aſcends up into the Plant as well as the Water.* There was much more terreſtrial Matter at the end of the Experiment, in the Water of the Glaſſes F and G, that had no Plants in them, than in thoſe that had Plants. The *Garden-mould* diſſolved in the Glaſſes K and L was conſiderably diminiſhed, and carried off. Nay, the terreſtrial and vegetable Matter was born up in the Tubes filled with Sand, Cotton, *&c.* in that Quantity, as to be evident even to Senſe. And the Bodies in the Cavities of the other Tubes, that had their lower Ends immers'd in Water, wherein Saffron, Cochinele, *&c.* had been infuſed, were tinged with Yellow, Purple, *&c.*

If I may be permitted to look abroad a while, towards our Shores and Parts within the Verge of the Sea, theſe will preſent us with a large Scene of Plants, that, along with the Vegetable, take up into them meer mineral Matter alſo in great abundance. Such are our Sea-Purſlains, the ſeveral of *Alga's*, of Sampires, and other marine Plants. Theſe contain common Sea-ſalt, which is all one with the *Foſſil*, in ſuch plenty, as not only to be plainly diſtinguiſh'd on the Palate, but may be drawn forth of them in conſiderable quantity. Nay, there want not thoſe who affirm, there are Plants found that will yield *Nitre*, and other mineral Salts; of which indeed I am not ſo far ſatisfied, that I can depend on the Thing, and therefore give this only as an hint for Enquiry.

To go on with the vegetable Matter, how apt and how much diſpoſed this, being ſo very fine and light, is to attend Water in all its Motions, and follow it into each of its Receſſes, is manifeſt, not only from the Inſtances above alledg'd, but many others. Percolate it withal the Care imaginable: Filter it with never ſo many Filtrations, yet ſome terreſtrial Matter will remain. 'Tis true, the Fluid will be thinner every time than other, and more diſingaged of the ſaid Matter; but never wholly free and clear. I have filtred Water thorough ſeveral wholly free and clear Sheets of thick Paper; and, after that, through very cloſe fine Cloth twelve times doubled. Nay, I have done this over and over; and yet a conſiderable quantity of this Matter diſcover'd it ſelf in the Water after all. Now if it thus paſs Interſtices, that are ſo very ſmall and fine along with the Water, 'tis the leſs ſtrange it ſhould attend it in its paſſage through the Ducts and Veſſels of Plants. 'Tis true, filtering and diſtilling of Water intercepts and makes it quit ſome of the Earthy Matter it was before impregnated withal: But then that which continues with the Water after this, is fine and light; and ſuch conſequently, as is in a peculiar manner fit for the Growth and Nouriſhment of Vegetables. And this is the Caſe of Rainwater. The Quantity of terreſtrial Matter it bears up into the Atmoſphere, is not great.

But that which it does bear up, is mainly of that light kind of vegetable Matter; and that too perfectly diſſolved, and reduced to ſingle Corpuſcles, all fit to enter the Tubules and Veſſels of Plants: On which Account 'tis that this Water is ſo very fertile and prolifick.

The Reaſon, why in this Propoſition, I ſay, only a great part of the terreſtrial Matter that is mix'd with the Water, aſcends up with it into the Plant, is, becauſe all of it cannot. The mineral Matter is a great deal of it, not only groſs and ponderous, but ſcabrous and inflexible; and ſo not diſpoſed to enter the Pores of the Roots. And a great many of the ſimple vegetable Particles by degrees unite, and form ſome of them ſmall Clods or *Moleculæ*; ſuch as thoſe mention'd in H, K, and L, ſticking to the Extremities of the Roots of thoſe Plants. Others of them intangle in a looſer manner; and form the *Nubeculæ*, and green Bodies, ſo commonly obſerved in ſtagnant Water. Theſe, when thus conjoin'd, are too big to enter the Pores, or aſcend up the Veſſels of Plants, which ſingly they might have done. They who are converſant in Agriculture, will eaſily ſubſcribe to this. They are well aware that, be their Earth never ſo rich, ſo good, and ſo fit for the Production of Corn or other Vegetables, little will come of it, unleſs the Parts of it be ſeparated and looſe. 'Tis on this Account they beſtow the Pains they do in Culture of it, in Digging, Plowing, Harrowing, and Breaking of the Clodded Lumps of Earth. 'Tis the ſame way that Sea-ſalt, Nitre, and other Salts promote Vegetation. I am ſorry I cannot ſubſcribe to the Opinion of thoſe Learned Gentlemen, who imagine Nitre to be eſſential to Plants; and that nothing in the vegetable Kingdom is tranſacted without it. By all the Trials I have been able to make, the thing is quite otherwiſe; and when contiguous to the Plant, it rather deſtroys than nouriſhes it. But this Nitre and other Salts certainly do; they looſen the Earth, and ſeparate the concreted Parts of; by that means fitting and diſpoſing them to be aſſumed by the Water, and carried up into the Seed or Plant, for its Formation and Augment. There's no Man but muſt obſerve, how apt all ſorts of Salts are to be wrought upon by Moiſture; how eaſily they liquate and run with it; and when theſe are drawn off, and have deſerted the Lumps wherewith they were incorporated, thoſe muſt moulder immediately, and fall aſunder of Courſe. The hardeſt Stone we meet with, if it happen, as frequently it does, to have any ſort of Salt intermix'd with the Sand of which it conſiſts, upon being expos'd to an humid Air, in a ſhort time diſſolves and crumbles all to pieces; and much more will clodded Earth or Clay, which is not of near ſo compact and ſolid a Conſtitution as Stone is. The ſame way likewiſe is Lime ſerviceable in this Affair. The Husbandmen ſay of it, that it does not fatten, but only mellows the Ground: By which they mean, that it does not contain any thing in it ſelf that is of the ſame Nature with the vegetable Mould, or afford any Matter fit for the Formation of Plants; but meerly ſoftens and relaxes the Earth; by that means rendering it more capable of entering the Seeds and Vegetables ſet in it, in order to their Nouriſhment, than otherwiſe it would have been. The Properties of Lime are well known; and how apt 'tis to be put into Ferment and Commotion by Water. Nor can ſuch Commotion ever happen when Lime is mix'd with Earth, however hard and clodded that may be, without opening and looſening of it.

4. *The Plant is more or leſs nouriſh'd and augmented, in proportion as the Water, in which it ſtands, contains a greater or ſmaller Quantity of proper terreſtrial Matter in it.* The Truth of this Propoſition is ſo eminently diſcernible through the whole Proceſs of theſe Trials, that I think no doubt can be made of it. The *Mint* in the Glaſs C was of much the ſame Bulk and Weight with thoſe in A and B. But the Water, in which that was, being River-water, which was apparently ſtored more copiouſly with terreſtrial Matter, than the Spring or Rain-water, wherein they ſtood, were; it had thriven to almoſt double the Bulk that either of them had, and with a leſs Expence of Water too. So likewiſe the Mint in L, in whoſe Water was diſſolved a ſmall quantity of good Garden-mould, tho' it had the diſadvantage * to be leſs, when firſt ſet, than either of the Mints in H or I, whoſe Water was the very ſame with this in L, but had none of that Earth mix'd with it; yet, in a ſhort time the Plant

* *Confer. Prop.* 1. *ſupra.*

not only overtook, but much out-ſtripp'd thoſe, and at the end of the Experiment was very conſiderably bigger and heavier than either of them. In like manner the *Mint* in N, tho' leſs at the beginning than that in M, being ſet in that thick, turbid, feculent Water, that remained behind, after that, wherein M was placed, was ſtill'd off, had in fine more than doubled its original weight and bulk; and received above twice the additional Encreaſe, than that in M, which ſtood in the thinner diſtill'd Water, had done. And, which is not leſs conſiderable, had not drawn off half the Quantity of Water that that had.

Why, in the beginning of this Article, I limit the Proportion of the Augment of the Plant to the Quantity of proper terreſtrial Matter in the Water, is, becauſe all, even the vegetable Matter, to ſay nothing of the Mineral, is not proper for the Nouriſhment of every Plant. There may be, and doubtleſs are, ſome Parts in different Species of Plants, that may be much alike, and ſo owe their Supply to the ſame common Matter; but 'tis plain all cannot. And there are other Parts ſo differing, that 'tis no ways credible they ſhould be form'd all out of the ſame ſort of Corpuſcles. So far from it, that there want not good Indications, as we ſhall ſee by and by, that every kind of Vegetable requires a peculiar and ſpecifick Matter for its Formation and Nouriſhment. Yea, each Part of of the ſame Vegetable does ſo; and there are very many and different Ingredients go to the Compoſition of the ſame individual Plant.

If therefore the Soil, wherein any Vegetable or Seed is planted, contains all or moſt of theſe Ingredients, and thoſe in due quantity, 'twill grow and thrive there; otherwiſe 'twill not. If there be not as many ſorts of Corpuſcles as are requiſite for the Conſtitution of the main and more eſſential Parts of the Plant, 'twill not proſper at all. If there be theſe, and not in ſufficient Plenty, 'twill ſtarve, and never arrive to its natural Stature: Or if there be any the leſs neceſſary and eſſential Corpuſcles wanting, there will be ſome Failure in the Plant; 'twill be defective in Taſte, in Smell, in Colour, or ſome other way. But tho' a Tract of Land may happen not to contain Matter proper for the Conſtitution of ſome one peculiar kind of Plant; yet it may for ſeveral others, and thoſe much differing among themſelves. The vegetative Particles are commix'd and blended in the Earth, with all the diverſity and variety, as well as all the uncertainty conceivable. I have given ſome Intimations of this elſewhere †, and ſhall not repeat them here, but hope in due time to put them into a much better Light than that they there ſtand in.

† *Nat. Hiſt. Earth*, p. 228. & ſeq.

It is not poſſible to imagine, how one uniform, homogeneous Matter, having its Principles or Original Parts all of the ſame Subſtance, Conſtitution, Magnitude, Figure, and Gravity, ſhould ever conſtitute Bodies ſo egregiouſly unlike, in all thoſe reſpects, as Vegetables of different kinds are; nay, even as the different Parts of the ſame Vegetable. That one ſhould carry a reſinous, another a milky, a third a yellow, a fourth a red Juice, in its Veins; one afford a fragrant, another an offenſive Smell; one be ſweet to the Taſte, another bitter, acid, acerbe, auſtere, *&c.* that one ſhould be nouriſhing, another poiſonous, one purging, another aſtringent: In brief, that there ſhould be that vaſt difference in them, in their ſeveral Conſtitutions, Makes, Properties, and Effects, and yet all ariſe from the very ſame ſort of Matter, would be very ſtrange. And, to note by the by, this Argument makes equally ſtrong againſt thoſe, who ſuppoſe meer Water the Matter out of which all Bodies are form'd.

The *Cataputia* in the Glaſs E received but very little Encreaſe, only three Grains and an half all the while it ſtood, tho' 2501 Grains of Water were ſpent upon it. I will not ſay the reaſon was, becauſe that Water did not contain in it Matter fit and proper for the Nouriſhment of that peculiar and remarkable Plant. No, it may be the Water was not a proper *Medium* for it to grow in; and we know there are very many Plants that will not thrive in it. Too much of that Liquor, in ſome Plants, may probably hurry the terreſtrial Matter thorough their Veſſels too faſt for them to arreſt and lay hold of it. Be that as it will, 'tis moſt certain there are peculiar Soils that ſuit particular Plants. In *England*, Cherries are obſerved to ſucceed beſt in *Kent*; Apples in *Herefordſhire*; Saffron in *Cambridgeſhire*; Wood in two or three of our *Midland Counties*; and Teazles in *Somerſetſhire*. This is an Obſervation that hath held in all Parts, and indeed in all Ages of the World. The moſt ancient Writers of Husbandry * took notice of it; and are not wanting in their Rules for making choice of Soils ſuited to the Nature of each kind of Vegetable they thought valuable, or worth propagating.

* *Vid. Varronem, Columellam, & reliquos Rei Ruſticæ Scriptores.*

But, which is a further Proof of what I am here endeavouring to advance, that Soil that is once proper and fit for the Production of ſome one ſort of Vegetable, does not ever continue to be ſo. No, in Tract of time it loſes that Property; but ſooner in ſome Lands, and later in others: This is what all who are converſant in theſe things know very well. If Wheat, for Example, be ſown upon a Tract of Land that is proper for that Grain, the firſt Crop will ſucceed very well; and perhaps the ſecond, and the third, as long as the Ground is in Heart, as the Farmers ſpeak; but in a few Years 'twill produce no more, if ſowed with that Corn: Some other Grain indeed it may, as Barly. And after this has been ſown ſo often, that the Land can bring forth no more of the ſame, it may afterwards yield good Oats; and, perhaps, Peaſe after them. At length 'twill become barren; the vegetative Matter, that at firſt it abounded withal, being educed forth of it by thoſe ſucceſſive Crops, and moſt of it born off. Each ſort of Grain takes forth that peculiar Matter that is proper for its own Nouriſhment. Firſt, the Wheat draws off thoſe Particles, that ſuit the Body of that Plant; the reſt lying all quiet and undiſturbed the while. And when the Earth has yielded up all them, thoſe that are proper for Barly, a different Grain, remain ſtill behind, 'till the ſucceſſive Crops of that Corn fetch them forth too. And ſo the Oats, and Peaſe, in their Turn; 'till in fine all is carried off, and the Earth in great meaſure drain'd of that ſort of Matter.

After all which, that very Tract of Land may be brought to produce another Series of the ſame Vegetables; but never 'till 'tis ſupplied with a new Fund of Matter, of like ſort with that it at firſt contain'd. This Supply is made ſeveral ways: By the Grounds lying fallow for ſome time, 'till the Rain has pour'd down a freſh Stock upon it: Or, by the Tiller's Care in manuring of it. And for farther Evidence that this Supply is in reality of like ſort, we need only reflect a while upon thoſe Manures that are found by conſtant experience beſt to promote Vegetation, and the Fruitfulneſs of the Earth. Theſe are chiefly either parts of Vegetables, or of Animals; which indeed either derive their own Nouriſhment immediately from vegetable Bodies, or from other Animals that do ſo. In particular, the Blood, Urine, and Excrements of Animals; Shavings of Horns, and of Hoofs; Hair, Wool, Feathers; calcin'd Shells; Lees of Wine, and of Beer; Aſhes of all ſorts of vegetable Bodies; Leaves, Straw, Roots, and Stubble, turn'd into the Earth by plowing or otherwiſe, to rot and diſſolve there: Theſe, I ſay, are our beſt Manures; and, being vegetable Subſtances, when refunded back again into the Earth, ſerve for the Formation of other like Bodies.

Not wholly to confine our Thoughts to the Fields, let us look a while into our Gardens; where we ſhall meet with ſtill further Confirmations of the ſame thing. The Trees, Shrubs, and Herbs cultivated in theſe, after they have continued in one Station, 'till they have derived thence the greater part of the Matter fit for their Augment, will decay and degenerate, unleſs either freſh Earth, or ſome fit Manure, be applied unto them. 'Tis true, they may maintain themſelves there for ſome time, by ſending forth Roots further and further to a great extent all round, to fetch in more remote Proviſion; but at laſt all will fail; and they muſt either have a freſh Supply brought to them, or they themſelves be removed and tranſplanted to ſome Place better furniſhed with Matter for their Subſiſtence. And accordingly *Gardiners* obſerve, that Plants that have ſtood a great while in a Place, have longer Roots than uſual; part of which they cut off, when they tranſplant them to a freſh Soil, as now not of any further uſe to them. All theſe Inſtances, to paſs over a great many others that might be alledged, point forth a particular terreſtrial Matter, and not Water, for the Subject to which Plants owe their Increaſe. Were it Water only, there would be no need of Manures; or of tranſplanting them from place to place. The Rain falls in all Places alike; in this Field and in that indifferently; in one ſide of an Orchard or Garden, as well as another. Nor could there be any reaſon, why a Tract of Land ſhould yield Wheat one Year, and not the next; ſince the Rain ſhowers down alike in each. But I am ſenſible I have carried on this Article to too great a length; which yet on ſo ample and extenſive a Subject, 'twas not eaſie to avoid.

5. *Vegetables are not form'd of Water; but of a certain peculiar Terreſtrial Matter.* It hath been ſhewn, that there is a conſiderable Quantity of this Matter contain'd both in Rain, Spring, and River-water: That the much greateſt part of the fluid Maſs that aſcends up into Plants, does not ſettle or abide there, but paſſes through the Pores of them, and *exhales* up into the Atmoſphere: That a great part of the terreſtrial Matter, mix'd with the Water, paſſes up into the Plant along with it; and that the Plant is more or leſs augmented in proportion, as the Water contains a greater or ſmaller Quantity of that Matter. From all which we may very reaſonably infer, that *Earth, and not Water, is the Matter that conſtitutes Vegetables.* The Plant in E drew up into it 2501 Grains of the fluid Maſs; and yet had received but Gr. 3 and a half of Increaſe from all that. The Mint in L, tho' it had at firſt the diſadvantage to be much leſs than that in I; yet being ſet in Water wherewith Earth was plentifully mix'd, and *that* in I *only in Water* without any ſuch additional Earth, it had vaſtly outgrown the other, weighing at laſt 145 Gr. more than that did, and ſo having gain'd about twice as much as that had. In like manner that in K, tho' 'twas a great deal leſs than when put in that in I, and alſo was impair'd and offended by Inſects; yet being planted in Water wherein Earth was diſſolved, whereas the Water in which it

ſtood had none, it not only over-took, but conſiderably ſurpaſs'd the other; weighing at laſt 29 Gr. more than that in I, and yet had not expended ſo much Water as that by above 2400 Gr. The Plant in N, tho' at firſt a great deal leſs than that in M; yet being ſet in the foul craſs Water that was left in the Still, after that,in which M was ſet, was drawn off, in Concluſion had gain'd in weight above double what that in the finer and thinner Water had. The Proportion of the Augment of that Plant that throve moſt was, to the fluid Maſs ſpent upon it, but as 1 to 46. In others, 'twas but as 1 to 60, 100, 200; nay, in the Cataputia, 'twas but as 1 to 714. The Mint in B took up 39 Gr. of Water a-day, one day with another; which was much more than the whole weight of the Plant originally; and yet, with all this, it gain'd not one fourth of a Grain a-day in weight. Nay, that in H took up 253 Gr. a-day of the Fluid: which was near twice as much as its original weight,it weighing, when firſt ſet in the Water, but 127 Grains. And, after all, the daily Encreaſe of the Plant was no more than Gr. $2\frac{15}{56}$.

6. *Spring, and Rain-water, contain pretty near an equal Charge of vegetable Matter; River-water more than either of them.* The Plants in the Glaſſes A, B, and C, were at firſt of much the ſame ſize and weight. At the End of the Experiment, the Mint in A had gain'd 15 Gr. out of 2558 Gr. of Spring-water; that in B,Gr. 17 and an half,out of 3004 Gr. of Rain-water; but that in C had got 26 Gr. out of

only 2493 Gr. of River-water. I do not found this Propoſition ſolely upon theſe Trials; having made ſome more, which I do not relate here, that agree well enough with theſe. So that the Proportions here delivered, will hold for the main; but a ſtrict and juſt Compariſon is hardly to be expected. So far from it, that I make no doubt, but the Water that falls in Rain, at ſome times, contains a greater ſhare of terreſtrial Matter than that which falls at others. A more powerful and intenſe Heat muſt needs hurry up a larger quantity of that Matter along with the humid Vapors that form Rain, than one more feeble and remiſs ever poſſibly can. The Water of one Spring may flow forth with an higher Charge of this Matter, than that of another; this depending partly upon the quickneſs of the Ebullition of the Water, and partly upon the Quantity of that Matter latent in the *Strata*, through which the Fluid paſſes, and the greater or leſs laxity of thoſe *Strata*. For the ſame reaſon, the Water of one River may abound with it more than that of another. Nay, the ſame River, when much agitated and in commotion, muſt bear up more of it, than when it moves with leſs rapidity and violence. That there is a great quantity of this Matter in Rivers; and that it contributes vaſtly to the ordinary Fertility of the Earth, we have an illuſtrious Inſtance in the *Nile*, the *Ganges*, and other Rivers that yearly overflow the neighbouring Plains. Their Banks ſhew the faireſt and largeſt Crops of any in the whole World. They are even loaded with the multitude of their Productions; and thoſe who have not ſeen them, will hardly be induced to believe the mighty Returns thoſe Tracts make in compariſon of others, that have not the Benefit of like Inundations.

7. *Water ſerves only for a Vehicle to the terreſtrial Matter, which forms Vegetables; and does not it ſelf make any addition unto them.* Where the proper terreſtrial Matter is wanting, the Plant is not augmented, tho' never ſo much Water aſcend into it. The *Cataputia* in E took up more Water than the Mint in C, and yet had grown but very little, having received only three Grains and an half of additional weight; whereas the other had received no leſs than twenty ſix Grains. The Mint in I was planted in the ſame ſort of Water as that in K was; only the latter had Earth diſſolved in the Water; and yet that drew off 13140 Gr. of the Water, gaining it ſelf no more than 139 Gr. in weight; whereas the other took up but 10731 Gr. of the Water, and was augmented 168 Gr. in weight. Conſequently that ſpent 2409 Gr. more of the Water than this in K did, and yet was not ſo much encreaſed in weight as this by 29 Gr. The Mint in M ſtood in the very ſame kind of Water as that in N did. But the Water in M having much leſs terreſtrial Matter in it than that in N had, the Plant bore up 8803 Gr. of it, gaining it ſelf only 41 Gr. the while; whereas that in N drew off no more than 4344 Gr. and yet was augmented 94 Gr. So that it ſpent 4459 Gr. of Water more than that did; and yet was not it ſelf ſo much in-

creaſed in weight, as that was by 53 Gr. This is both a very fair, and a very concluſive Inſtance; on which Account 'tis that I make oftner uſe of it. Indeed they are all ſo; and to add any thing further on this Head, will not be needful.

'Tis evident therefore Water is not the Matter that compoſes Vegetable Bodies. 'Tis only the Agent that conveys that Matter to them; that introduces and diſtributes it to their ſeveral Parts for their Nouriſhment. That Matter is ſluggiſh and unactive, and would lye eternally confin'd to its Beds of Earth, without ever advancing up into Plants, did not Water, or ſome like Inſtrument, fetch it forth and carry it unto them. That therefore there is that plentiful Proviſion, and vaſt Abundance of it ſupplied to all Parts of the Earth, is a mark of a natural Providence ſuperintending over the Globe we inhabit; and ordaining a due Diſpenſation of that Fluid, without the Miniſtry of which the Noble Succeſſion of Bodies we behold, *Animals*, *Vegetables*, and *Minerals*, would be all at a ſtand †. But to keep to Plants, 'tis manifeſt Water, as well on this, as upon the other Hypotheſis, is abſolutely neceſſary in the Affair of Vegetation; and it will not ſucceed without it: Which indeed gave occaſion to the Opinion, that Water it ſelf nouriſhed, and was changed into vegetable Bodies. They ſaw, tho' theſe were planted in a Soil never ſo rich, ſo happy, ſo advantageous, nothing came of it unleſs there was Water too in a conſiderable quantity

† *Conf. Nat. Hiſt. Earth*, p. 47. & ſeq. uti & p. 128, *&c.*

quantity. And it muſt be allow'd Vegetables will not come on or proſper where that is wanting: But yet what thoſe Gentlemen inferr'd thence, was not, we ſee, well grounded.

This Fluid is capacitated for the Office here aſſign'd it ſeveral ways: By the Figure of its Parts; which, as appears from many Experiments, is exactly and mathematically Spherical; their Surfaces being perfectly polite, and without any the leaſt Inequalities. 'Tis evident, Corpuſcles of ſuch a Figure are eaſily ſuſceptible of motion, yea, far above any others whatever; and conſequently the moſt capable of moving and conveying other Matter, that is not ſo active and voluble. Then the Intervals of Bodies of that Figure are, with reſpect to their bulk, of all others the largeſt; and ſo the moſt fitted to receive and entertain foreign Matter in them. Beſides, as far as the Trials hitherto made inform us, the conſtituent Corpuſcles of Water are each ſingly conſider'd abſolutely ſolid; and do not yield to the greateſt external Force. This ſecures their Figure againſt any Alteration; and the Intervals of the Corpuſcles muſt be always alike. By the latter, 'twill be ever diſpoſed to receive Matter into it; and by the former, when once received, to bear it on along with it. Water is further capacitated to be a Vehicle to this Matter, by the tenuity and fineneſs of the Corpuſcles of which it conſiſts. We hardly know any Fluid in all Nature, except Fire, whoſe conſtituent Parts are ſo exceeding ſubtle and ſmall as thoſe of Water are. They'll paſs

Pores and Interſtices, that neither Air nor any other Fluid will. This enables them to enter the fineſt Tubes and Veſſels of Plants, and to introduce the terreſtrial Matter, conveying it to all Parts of them; whilſt each, by means of Organs 'tis endowed with for the purpoſe, intercepts and aſſumes into it ſelf ſuch Particles as are ſuitable to its own Nature, letting the reſt paſs on through the common Ducts. Nay, we have almoſt every where Mechanical Inſtances of much the ſame Tenor. 'Tis obvious to every one how eaſily and ſuddenly Humidity, or the Corpuſcles of Water ſuſtained in the Air, pervade and inſinuate themſelves into Cords, however tightly twiſted, into Leather, Parchment, Vegetable Bodies, Wood, and the like. This it is that fits them for *Hygrometers*; and to meaſure and determine the different quantities of Moiſture in the Air, in different Places and Seaſons. How freely Water paſſes and carries with it terreſtrial Matter, through Filtres, Colatures, Diſtillations, &c. hath been intimated already.

8. *Water is not capable of performing this Office to Plants, unleſs aſſiſted by a due Quantity of Heat; and this muſt concur, or Vegetation will not ſucceed.* The Plants that were ſet in the Glaſſes Q, R, S, &c. in *October*, and the following colder Months, had not near the quantity of Water ſent up into them, or ſo great an additional Encreaſe by much, as thoſe that were ſet in *June*, *July*, and the hotter. 'Tis plain Water has no power of moving it ſelf; or riſing to the vaſt height it does in the more

tall and lofty Plants. So far from this, that it does not appear from any Diſcovery yet made, that even its own Fluidity conſiſts in the inteſtine motion of its Parts; whatever ſome otherwiſe very learned and knowing Perſons may have thought. There's no need of any thing more, for ſolving all the *Phænomena* of Fluidity, than ſuch a Figure and Diſpoſition of the Parts, as Water has. Corpuſcles of that make, and that are all abſolutely Spherical, muſt ſtand ſo very tickle and nicely upon each other, as to be ſuſceptible of every Impreſſion; and, tho' not perpetually in motion, yet muſt be ever ready and liable to be put into it, by any the ſlighteſt Force imaginable. It is true, the Parts of Fire or Heat are not capable of moving themſelves any more than thoſe of Water; but they are more ſubtil, light, and active, than thoſe are, and ſo more eaſily put into motion. In fine, 'tis evident and matter of Fact, that Heat does operate upon, and move the Water, in order to its carrying on the Work of Vegetation: But how 'tis agitated it ſelf, and where the motion firſt begins, this is no fit Place to enquire.

That the Concourſe of Heat in this Work is really neceſſary, appears, not only from the Experiments before us, but from all Nature; from our Fields and Foreſts, our Gardens and our Orchards. We ſee in *Autumn*, as the Sun's Power grows gradually leſs and leſs, ſo its Effects on Plants is remitted, and their Vegetation ſlackens by little and little. Its Failure is firſt diſcernible in Trees. Theſe are raiſed higheſt above the Earth; and require a more intenſe Heat to elevate the Water, charged with their Nouriſhment, to the Tops and Extremeties of them. So that for want of freſh Support und Nutriment, they ſhed their Leaves, unleſs ſecured by a very firm and hardy Conſtitution indeed, as our *ever-Greens* are. Next the Shrubs part with theirs; and then the Herbs and lower Tribes; the Heat being at length not ſufficient to ſupply even theſe, tho' ſo near the Earth, the Fund of their Nouriſhment. As the Heat returns the ſucceeding Spring, they all recruit again; and are furniſh'd with freſh Supplies and Verdure: But firſt, thoſe which are loweſt and neareſt the Earth, Herbs, and they that require a leſſer degree of Heat to raiſe the Water with its Earthy Charge into them: Then the Shrubs and higher Vegetables in their Turns; and laſtly, the Trees. As the Heat increaſes, it grows too powerful, and hurries the Matter with too great Rapidity thorough the finer and more tender Plants: Theſe therefore go off, and decay; and others that are more hardy and vigorous, and require a greater ſhare of Heat, ſucceed in their Order. By which Mechaniſm, provident Nature furniſhes us with a very various and differing Entertainment; and what is beſt ſuited to each Seaſon, all the Year round.

As the Heat of the ſeveral Seaſons affords us a different Face of Things; ſo the ſeveral diſtant Climates ſhew different Scenes of Nature, and Productions of the Earth *. The Hotter Countries yield ordinarily the largeſt and talleſt Trees; and thoſe in too much greater variety than the colder ever do. Even thoſe Plants which are common to both, attain to a much greater Bulk in the Southern than in the Northern Climes. Nay, there are ſome Regions ſo bleak and chill, that they raiſe no Vegetables at all to any conſiderable ſize. This we learn from *Groenland*, from *Iſland*, and other Places of like cold Site and Condition. In theſe no Tree ever appears; and the very Shrubs they afford, are few, little, and low.

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* *Conſ. Nat. Hiſt. Earth*, Pag. 267. & ſeq.

Again, in the warmer Climates, and ſuch as do furniſh forth Trees and the larger Vegetables, if there happen a remiſſion or diminution of the uſual Heat, their Productions will be impeded and diminiſhed in proportion. Our late Colder Summers have given us proof enough of this. For tho' the Heat we have had, was ſufficient to raiſe the vegetative Matter into the lower Plants, into our Corns, our Wheat, Barly, Peaſe, and the like; and we have had plenty of Straw-berries, Rasberries, Currans, Goosberries, and the Fruits of ſuch other Vegetables as are low and near the Earth: Yea, and a moderate ſtore of Cherries, Mulberries, Plumbs, Filberts, and ſome others that grow ſomewhat at a greater Height; yet our Apples, our Pears, Walnuts, and the Productions of the taller [†] Trees have been fewer, and thoſe not ſo kindly, ſo thoroughly ripen'd, and brought to that Perfection they

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[*] *The Dwarf-Apple and Pear-trees have ſucceeded better. And indeed in Trees of the ſame kind, thoſe that keep cloſeſt to the Earth always produce the moſt and beſt Fruit. For which Reaſon 'tis that the Gardiners check and reſtrain the Growth of their better Fruit-trees, and prevent their running up to too great a Height.*

were in the former more benign and warm Seaſons. Nay, even the lower Fruits and Grains have had ſome ſhare in the common Calamity; and fallen ſhort both in Number and Goodneſs of what the hotter and kinder Seaſons were wont to ſhew us. As to our Grapes, Abricots, Peaches, Nectarins, and Figs, being tranſplanted hither out of hotter Climes, 'tis the leſs wonder we have of late had ſo general a Failure of them.

Nor is it the Sun, or the ordinary emiſſion of the Subterranean Heat only, that promotes Vegetation; but any other indifferently, according to its Power and Degree: This we are taught by our Stoves, hot Beds, and the like. All Heat is of like kind; and whereever is the ſame Cauſe, there will be conſtantly the ſame Effect. There's a Procedure in every part of Nature, that is perfectly regular and geometrical, if we can but find it out; and the further our Searches carry us, the more ſhall we have occaſion to admire this, and the better 'twill compenſate our Induſtry.

An Account of the Meaſure of the thickneſs of Gold upon Gilt Wire; together with a Demonſtration of the exceeding Minuteneſs of the Atoms or conſtituent Particles of Gold; as it was read before the R. Society, *by* E. Halley.

WHAT are the conſtituent parts of Matter, and how there comes to be ſo great a diverſity in the weight of Bodies, to all appearance equally ſolid and denſe, ſuch as are Gold and Glaſs, (whoſe ſpecifick Gravities are nearly as 7 to 1) ſeems a very hard Queſtion to thoſe that ſhall rightly conſider it: For from undoubted Experiment, Gravity is in all Bodies proportionable to the quantity of Matter in each; and there is no ſuch thing as a propenſion of ſome more, others leſs, towards the Earth's Center; ſince the Impediment of the Air being removed, all Bodies deſcend, be they never ſo looſe or compact in texture, with equal Velocity. It follows therefore, That there is 7 times as much Matter in Gold, as in a Piece of Glaſs of the ſame Magnitude; and conſequently, that at leaſt ſix parts of ſeven in the Bulk of of Glaſs, muſt be Pore or Vacuity: This ſome Favourers of the Atomical Philoſophy have endeavoured to ſolve, by ſuppoſing the primary or conſtituent Atoms of Gold to be much larger than thoſe of other Bodies, and conſequently the Pores fewer; whereas in other Bodies, the great multitude of the interſperſed Vacuities does diminiſh their Weights.

Being deſirous to examine this Notion of the Magnitude of Atoms of Gold, I bethought my ſelf of the extreme Ductility of that Metal, which is ſeen in the beating of it into Leaf, and above all in the drawing fine Gilt-wire, by means whereof, I believed I might moſt exactly obtain the true thickneſs of the Coat of Gold, that appears, even with the Microſcope, ſo well to repreſent Gold it ſelf, that not the leaſt point of Silver appears through it. In order to this, I inform'd my ſelf among the Wire-drawers, what Gold they us'd to their Silver; and they told me, that the very beſt double Gilt Wire was made out of Cylidrick Ingots, 4 Inches in Circumference, and 28 Inches long, which weigh 16 Pounds Troy; on theſe they beſtow 4 Ounces of Gold, that is, to every 48 Ounces of Silver one of Gold; and that two Yards of the ſuper-fine Wire weighs a Grain. Hence at firſt ſight it appear'd, that the length of 98 Yards is in weight 49 Grains, and that a ſingle Grain of Gold covers the ſaid 98 Yards, and that the 10000th part of a Grain is above $\frac{1}{3}$ of an Inch long; which yet may be actually divided into 10, and ſo the 100000th part of a Grain of Gold be viſible without a Microſcope. But being deſirous to compute the thickneſs of the Skin of Gold, by means of the ſpecifick Gravities of the Metals, *viz.*

Silver $10\frac{1}{3}$, and Gold $18\frac{2}{3}$, I found the Diameter of ſuch Wire the $\frac{1}{386}$ part of an Inch, and its Circumference the $\frac{1}{123}$ part; but the Gold in thickneſs no to exceed the $\frac{1}{134500}$ part of an Inch; whence it may be concluded, that the Cube of the hundreth part of an Inch would contain above 2433000000, (or the Cube of 1345) of ſuch Atoms. And it may likewiſe be marvelled at, that Gold being ſtretcht to ſo great a degree as is here demonſtrated, ſhould yet ſhew it ſelf of ſo even and united a Texture, as not to let the white Colour of the Silver under it appear through any the leaſt Pores; which argues, that even in this exceeding thinneſs very many of thoſe Atoms may ſtill lie one over the other: Which is a Conſideration may merit the Thoughts of this Honourable Society, as tending to examine that renowned Atomical Doctrine, which has of late much obtained among the Learned.

An Account of the ſeveral Species of Infinite Quantity, *and of the Proportions they bear one to the other, as it was read before the* Royal Society, *by.* E. Halley.

THAT all Magnitudes infinitely great, or ſuch as exceed any aſſignable Quantity, are equal among themſelves, though it it be vulgarly received for a Maxim, is not yet ſo common as it is erroneous; and the reaſon of the miſtake ſeems to be, That the Mind of Man, coming to contemplate the Extenſions of what exceeds the bounds of its Capacity, and of which the very Idea does include a negation of Limits; it comes to paſs that we acquieſce generally, and it ſuffices to ſay ſuch a Quantity is infinite.

But if we come more nearly to examine this Notion, we ſhall find, that there are really beſides infinite *Length* and infinite *Area*, no leſs than Three ſeveral ſorts of infinite Solidity; all of which are *Quantitates ſui generis*, having no more relation or proportion the one to the other, than a Line to a Plane, or a Plane to a Solid, or a Finite to an Infinite: But that among themſelves, each of thoſe Species of Infinites are in given Proportions, is what I now intend to make plain, if poſſible.

But firſt, infinite Length, or a Line infinitely long, is to be conſidered either as beginning at a Point, and ſo infinitely extended one way, or elſe both ways from the ſame Point; in which caſe the one, which is a beginning Infinity, is the one half of the whole, which is the Summ of the beginning and ceaſing Infinity; or, as I may ſay, of Infinity, *a parte ante* and *a parte poſt*: Which is analogous to Eternity in time or duration, in which there is always as much to follow as is paſt, from any point or moment of Time: Nor doth the Addition or Subduction of finite Length or Space of time alter the caſe either in Infinity or Eternity, ſince both the one or the other cannot be any part of the whole.

As to infinite *Surface* or *Area*, any right Line, infinitely extended both ways on an infinite Plane, does divide that infinite Plane into equal Parts; the one to the right, and the other to the left of the ſaid Line: But if from any Point in ſuch a Plane, two right Lines be infinitely extended, ſo as to make an Angle, the infinite Area, intercepted between thoſe infinite right Lines, is to the whole infinite Plane, as the Arch of a Circle, on the Point of Concourſe of thoſe Lines, as a Centre, intercepted between the ſaid Lines, is to the Circumference of the Circle; or as the Degrees of the Angle to the 360 Degrees of a Circle. For Example, two right Lines meeting at a right Angle do include, on an infinite Plane, a quarter part of the whole infinite Area of ſuch a Plane.

But if ſo be, two parallel infinite Lines be ſuppoſed drawn on ſuch an infinite Plain, the

Area intercepted between them will be likewiſe infinite; but at the ſame time will be infinitely leſs, than that Space which is intercepted between two infinite Lines that are inclined, tho' with never ſo ſmall an Angle; for that in the one Caſe, the given finite diſtance of the parallel Lines diminiſhes the Infinity in one Degree of Dimenſion; whereas in a Sector, there is Infinity in both Dimenſions; and conſequently, the Quantities are the one infinitely greater than the other, and there is no proportion between them.

From the ſame Conſideration ariſe the Three ſeveral Species of infinite Space or Solidity, as has been ſaid; for a Parallelepipide, or a Cylinder, infinitely long, is greater than any finite Magnitude how great ſoever; and all ſuch Solids ſuppoſed to be formed on given Baſes, are as thoſe Baſes, in proportion to one another. But if two of theſe three Dimenſions are wanting, as in the ſpace intercepted between two parallel Planes infinitely extended, and at a finite diſtance; or with infinite Length and Breadth, with a finite Thickneſs; All ſuch Solids ſhall be as the given finite diſtances one to another: But theſe Quantities, tho' infinitely greater than the other, are yet infinitely leſs than any of thoſe, wherein all the three Dimenſions are infinite. Such are the Spaces intercepted between two inclined Planes infinitely extended; the Space intercepted by the Surface of a Cone, or the ſides of a Pyramid likewiſe infinitely continued, *&c.* of all which notwithſtanding, the Proportions one to another, and to the τὸ πᾶν or vaſt Abyſs of infinite Space (wherein is the *Locus* of all things that are or can be; or to the Solid of infinite Length, Breadth, and Thickneſs, taken all manner of ways) are eaſily aſſignable. For the Space between two Planes, is to the whole, as the Angle of thoſe Planes to the 360 Degrees of the Circle. As for Cones and Pyramids, they are as the Spherical Surface, intercepted by them, is to the Surface of the Sphere; and therefore Cones are as the verſed Sines of half their Angles, to the Diameter of the Circle: Theſe three ſorts of infinite Quantity are analogous to a Line, Surface and Solid, and after the ſame manner cannot be compared, or have any proportion the one to the other.

Beſides theſe, there are ſeveral other Species of infinite Quantity, ariſing from the Contemplation of Curves, and their Aſymptotes; which, by reaſon of the difficulty of the Subject, cannot be made ſo plain to moſt Readers: But what has been already ſaid, may be ſufficient to evince what we undertook to explain.

An

An Account of Dr. Robert Hook'*s Invention of the Marine Barometer, with its Deſcription and Uſes, publiſhed by order of the R. Society, by* E. Halley, *R. S. S.*

SInce it was found that the *Torricellian Tube*, commonly called the *Mercurial Barometer*, by the riſing and falling of the *Quick-ſilver* therein, doth preſage the Changes of the Air, in relation to fair and foul Weather; upon ſeveral Years obſervation of it, it has been proved and adjuſted for that purpoſe by Dr. *Robert Hook*; and there have been by him many attempts to improve the Inſtrument, and render the Minute Diviſions on the Scale thereof more ſenſible. He alſo judging that it might be of great uſe at Sea, contrived ſeveral ways to make it ſerviceable on Board Ship; one of which he explained to the *R. Society* at their weekly Meeting in *Greſham Colledge*, *January* 2. 166$^{7}_{8}$. ſince which time he hath further cultivated the Invention, and ſome Years ago produced before the ſaid *Society*, the Inſtrument I am now to deſcribe, which for its ſubtilty and uſefulneſs, ſeemeth to ſurpaſs all other performances of the like Nature.

'Till ſuch time as the Authors preſent Indiſpoſition will give him leave to beſtow freely his Thoughts on this Subject upon the Publick, it is the Opinion of the Society, that ſuch an account be given of this Contrivance, as may render it known, and recommend it to the Mariners uſe, for which it was principally intended.

The *Mercurial Barometer* requiring a perpendicular Poſture, and the *Quick-ſilver* vibrating therein with great violence upon any Agitation, is therefore uncapable of being uſed at Sea (though it hath lately been contrived to be made portable), ſo it remained to find out ſome other Principle, wherein the Poſition of the Inſtrument was not ſo indiſpenſably neceſſary: For this, all thoſe that uſe the Sea are obliged to the great facility Dr. *Hook* has always ſhewn, in applying Philoſophical Experiments to their proper uſes.

It is about forty Years ſince, that the *Thermometers* of *Robt. de Fluctibus*, depending on the Dilatation andContraction of included Air by Heat and Cold, have been diſuſed, upon diſcovery that the Airs preſſure is unequal; that inequality mixing itſelf with the effects of the warmth of the Air in that Inſtrument. And inſtead thereof was ſubſtituted the ſeal'd *Thermometer*, including Spirit of Wine (firſt brought into *England*, out of *Italy*, by Sir *Robert Southwell*) as a proper Standard of the temper of the Air in relation to Heat and Cold; that Ætherial Spirit being of all the known Liquors the moſt ſuſceptible of Dilatation and Contraction, eſpecially with a moderate degree of either Heat or Cold. Now this being allowed as a Standard, and the other *Thermometer* that includes Air being graduated with the ſame Diviſions, ſo as at the time when the Air was included, to agree with the Spirit-*Thermometer* in all the degrees of Heat and Cold, noting at the ſame time the preciſe height of the *Mercury* in the common Barometers: It will readily be underſtood, that whenſoever theſe two *Thermometers* ſhall agree, the preſſure of the Air is the ſame it was, when the Air was included and the Inſtrument graduated: That if in the Air-*Thermometer* the Liquor ſtand higher than the Diviſion marked thereon, correſponding with that on the Spirit-glaſs, it is an indication that there is a greater preſſure of the Air at that time, than when the Inſtrument was graduated. And the contrary is to be concluded when the Air-glaſs ſtands lower than the Spirit, *viz.* that then the Air is ſo much lighter, and the *Quick-ſilver* in the ordinary Barometer lower than at the ſaid time of Graduation.

And the ſpaces anſwering to an Inch of *Mercury* will be more or leſs, according to the quantity of Air ſo included, and the ſmallneſs of the Glaſs Cane, in which the Liquors riſes and falls, and may be augmented almoſt in any proportion, under that of the ſpecifick Gravity of the Liquor of the *Thermometer* to *Mercury*. So as to have a Foot or more for an Inch of *Mercury*, which is another great convenience.

It has been obſerved by ſome, that in long keeping this Inſtrument, the Air included either finds a means to eſcape, or depoſites ſome Vapours mixt with it, or elſe for ſome other cauſe becomes leſs Elaſtick, whereby, in proceſs of time, it gives the height of the *Mercury* ſomewhat greater than it ought; but this, if it ſhould happen in ſome of them, hinders not the uſefulneſs thereof, for that it may at any time very eaſily be corrected by experiment, and the riſing and falling thereof are the things chiefly remarkable in it, the juſt height being barely a Curioſity.

In theſe parts of the World, long experience has told us, that the riſing of the *Mercury* forebodes fair Weather after foul, and an Eaſterly or Northerly Wind; and that the falling thereof, on the contrary ſignifies Southerly or Weſterly Winds, with Rain, or ſtormy Winds, or both; which latter it is of much more conſequence to provide againſt at Sea than at Land; and in a Storm, the *Mercury* beginning to riſe is a ſure ſign that it begins to abate, as has been experienced in high Latitudes both to the Northwards and Southwards of the Æquator.

The Form of this Inſtrument is ſhown in the Cut by Tab. 4. Fig. 1. wherein, P.310.

A B repreſents the Spirit-*Thermometer*, graduated from 0, or the freezing Point, through all the poſſible degrees of the Heat or Cold of the Air, at leaſt in theſe Climates.

C D is the Air-*Thermometer*, graduated after the ſame manner with the like Degrees.

EF is a Plate applied to the ſide of the *Thermometer* CD, graduated into ſpaces anſwering to Inches and parts of an Inch of *Mercury*, in the common Barometers.

G, a Hand ſtanding on the Plate at the height of the *Mercury* thereon, as it was when the Inſtrument was graduated, as ſuppoſe here at 29½ Inches.

LM a Wire on which the Plate EF ſlips up and down, parallel to the Cane of the *Thermometer* CD.

K, any Point at which the Spirit ſtands at the time of obſervation; ſuppoſe at 38 on the Spirit-*Thermometer*; Slide the Plate EF 'till the Hand G ſtand at 38 on the Air-*Thermometer*, and if the Liquor therein ſtand at 38 likewiſe, then is the preſſure of the Air the ſame as at the time of Graduation, *viz.* 29, 5; but if it ſtand higher, as at 30, at I; then is the preſſure of the Air greater; and the diviſion on the ſliding Plate againſt the Liquor, ſhews the preſent height of the *Mercury* to be twenty nine Inches ſeven Tenths. And this may ſuffice as to the manner of uſing it.

I had one of theſe Barometers with me in my late Southern Voyage, and it never failed to prognoſtick and give early notice of all the bad Weather we had, ſo that I depended thereon, and made proviſion accordingly; and from my own experience I conclude, that a more uſeful contrivance hath not for this long time been offered for the benefit of Navigation.

Theſe Inſtruments are made according to the Direction of Dr. *Hook*, by Mr. *Henry Hunt*, Operator to the Royal Society, who will furniſh any Gentlemen with them, and give them directions how to uſe them.

A Diſcourſe concerning the Proportional Heat of the Sun in all Latitudes, with the Method of collecting the ſame, as it was read before the Royal Society in one of their late Meetings. By E. Halley.

THere having lately ariſen ſome Diſcourſe about that part of the Heat of Weather, ſimply produced by the Action of the Sun; and I having affirmed, that if that were conſidered, as the only Cauſe of the Heat of the Weather, I ſaw no reaſon, but that under the Pole the ſolſtitial Day ought to be as hot as it is under the Æquinoctial, when the Sun comes vertical, or over the Zenith: For this reaſon, that for all the 24 Hours of that Day under the Pole, the Sun's Beams are inclined to the Horizon, with an Angle of 23½ Degrees; and under the Æquinoctial, tho' he come vertical, yet he ſhines no more than 12 Hours, and is again 12 Hours abſent; and that for 3 Hours 8 Min. of that 12 Hours, he is not ſo much elevated as under the Pole; ſo that he is not 9 of the whole 24 higher than 'tis there, and is 15 Hours lower. Now the ſimple Action of the Sun is, as all other Impulſes or Stroaks, more or leſs forceable, according to the *Sinus* of the Angle of Incidence, or to the Perpendicular let fall on the Plain, whence the vertical Ray (being that of the greateſt Heat) being put *Radius*, the force of the Sun on the Horizontal Surface of the Earth will be to that, as the *Sinus* of the Sun's Altitude at any other time. This being allowed for true, it will then follow, that the time of the continuance of the Sun's ſhining being taken for a *Baſis*, and the *Sines* of the Sun's Altitudes erected thereon as Perpendiculars, and a Curve drawn through the Extreamities of thoſe Perpendiculars, the *Area* comprehended ſhall be proportionate to the Collection of the Heat of all the Beams of the Sun in that ſpace of time. Hence it will follow, that under the Pole the Collection of all the Heat of a tropical Day, is proportionate to a Rectangle of the *Sine* of 23½ *gr.* into 24 Hours or the Circumference of a Circle; that is, the *Sine* of 23½ *gr.* being nearly 4 Tenths of *Radius*; as $\frac{8}{10}$ into 12 Hours. Or the Polar Heat is equal to that of the Sun containing 12 Hours above the Horizon, at 53 *gr.* height, than which the Sun is not 5 Hours more elevated under the Æquinoctial.

But that this Matter may the better be underſtood, I have exemplied it by a Scheme (*Tab.* 4. *Fig.* 2.) wherein the *Area Z G H H*, is equal to the *Area* of all the *Sines* of the Sun's Altitude under the Æquinoctial, erected on the reſpective Hours from Sun-riſe to the Zenith; and the *Area* ♋ *H H* ♋ is in the ſame porportion to the Heat of the ſame 6 Hours under the Pole on the Tropical Day; and ⊙

H H Q, is proportional to the collected Heat of 12 Hours, or half a Day under the Pole, which ſpace ⊙ *H H Q* is viſibly greater than the other *Area H Z G H*, by as much as the *Area H G Q* is greater than the *Area Z G* ⊙; which, that it is ſo, is viſible to ſight, by a great exceſs; and ſo much in proportion does the Heat of the 24 Hours Sun ſhine under the Pole, exceed that of the twelve Hours under the Æquinoctial: Whence, *Cæteris paribus*, it is reaſonable to conclude, that were the Sun perpetually under the Tropick, the Pole would be at leaſt as warm, as it is now under the Line itſelf.

But whereas the Nature of Heat is to remain in the Subject, after the Cauſe that heated is removed, and particularly in the Air; under the Æquinoctial, the twelve Hours abſence of the Sun does very little ſtill the Motion impreſſed by the paſt Action of his Rays, wherein Heat conſiſts, before he ariſe again: But under the Pole the long abſence of the ⊙ for 6 Months, wherein the extreamity of Cold does obtain, has ſo chilled the Air, that it is as it were frozen, and cannot, before the Sun has got far towards it, be any way ſenſible of his preſence, his Beams being obſtructed by thick Clouds, and perpetual Foggs and Miſts, and by that Atmoſphere of Cold, as the late Honourable Mr. *Boyl* was pleaſed to term it, proceding from the everlaſting Ice, which in immenſe Quantities does chill the Neighbouring Air, and which the too ſoon retreat of the Sun leaves unthawed, to encreaſe again, during the long Winter that follows this ſhort interval of Summer. But the differing Degrees of Heat and Cold in differing Places, depend in great meaſure upon the Accidents of the Neighbourhood of high Mountains, whoſe height exceedingly chills the Air brought by the Winds over them; and of the Nature of the Soil, which variouſly retains the Heat, particularly the Sandy, which in *Africa*, *Arabia*, and generally where ſuch Sandy Deſarts are found, do make the Heat of the Summer incredible to thoſe that have not felt it.

In the proſecution of this firſt Thought, I have ſolved the Problem generally, *viz.* to give the proportional Degree of Heat, or the ſum of all the *Sines* of the Sun's Altitude, while he is above the Horizon in any oblique Sphere, by reducing it to the finding of the Curve Surface of a Cylindrick Hoof, or of a given part thereof.

Now this Problem is not of that difficulty as appears at firſt ſight, for in *Tab.*4.*Fig.* 3. let the Cylinder ABCD be cut obliquely with the Ellipſe BKDI, and by the Center thereof H, deſcribe the Circle IKLM; I ſay, the Curve Surface IKLB is equal to the Rectangle of IK and BL, or of HK and 2 BL or BC: And if there be ſuppoſed another Circle, as NQPO, cutting the ſaid Ellipſe in the Points P, Q; draw PS, QR, parallel to the Cylinders Axe, till they meet with the aforeſaid Circle IKLM in the Points R, S, and draw the Lines RTS, QVP biſected in T and V. I ſay again, that the Curve Surface RMSQDP is equal to the Rectangle of BL or MD and RS, or of 2 BL or AD and ST or VP; and the Curve Surface QNPD is equal to RS $\times$ MD---the Arch

RMS *x* SP, or the Arch MS *x* 2 SP : Or it is equal to the Surface RMSQDP, ſubſtracting the Surface RMSQNP. So likewiſe the Curve Surface QBPO is equal to the ſum of the Surface RMSQDP or RS *x* MD, and of the Surface RLSQOP, or the Arch LS *x* 2 SP.

This is the moſt eaſily demonſtrated from the Conſideration, That the Cylindrick Surface IKLB is to the inſcribed Spherical Surface IKLE, either in the whole, or in its Analogous Parts, as the tangent BL is to the Arch EL, and from the Demonſtrations of *Archimedes de Sphæra & Cylindro*, *Lib.* 1. *Prop.* XXX. and XXXVII. XXXIIX. which I ſhall not repeat here, but leave the Reader the pleaſure of examining it himſelf; nor will it be amiſs to conſult Dr. *Barrow*'s Learned Lectures on that Book, Publiſhed at *London*, *Anno.* 1684, *viz.* *Probl.* IX. and the Corollaries thereof.

Now to reduce our Caſe of the Sum of all the *Sines* of the Sun's Altitude in a given Declination and Latitude to the aforeſaid Problem, let us conſider (*Tab.*4. *Fig.*4.) which is the *Analemma* projected on the Plain of the *Meridian*, Z the Zenith, P the Pole, HH the Horizon, æ æ the Æquinoctial, ♋ ♋, ♑ ♑ the two Tropicks, ♋ I the *Sine* of the Meridian Altitude in ♋ ; and equal thereto, but perpendicular to the Tropick, erect ♋ 1, and draw the Line T 1 interſecting the Horizon in T, and the Hour Circle of 6, in the Point 4, and 6 4 ſhall be equal to 6R, or to the *Sine* of the Altitude at 6 : And the like for any other Point in the Tropick, erecting a Perpendicular thereat, terminated by the Line T 1 : Through the Point 4 draw the Line 4 5 7 parallel to the Tropick, and repreſenting a Circle equal thereto; then ſhall the Tropick ♋ ♋ in *Fig.* 4. anſwer to the Circle NOPQ, in *Fig.* 3. the Circle 457 ſhall anſwer the Circle IKLM, T 4 1 ſhall anſwer to the Elliptick Segment QIBKP, 6 R or 6 4 ſhall anſwer to SP, and 5 1 to BL, and the Arch ♋ T, to the Arch LS, being the ſemidiurnal Arch in that Latitude and Declination; the *Sine* whereof, tho' not expreſſible in *Fig.* 4. muſt be conceived as Analogous to the Line TS or UP in *Fig.* 3.

The Relation between theſe two Figures being well underſtood, it will follow from what precedes, That, *the ſum of the* Sines *of the Meridian Altitudes of the Sun in the two Tropicks, (and the like for any two oppoſite Parallels) being multiplied by the* Sine *of the ſemidiurnal Arch, will give an* Area *Analogous to the Curve Surface RMSQDP; and thereto adding in Summer, or ſubſtracting in Winter, the Product of the length of the ſemidiurnal Arch, (taken according to* Van Ceulen*'s Numbers) into the difference of the above-ſaid* Sines *of the Meridian Altitude: The ſum in one caſe and difference in another ſhall be as the Aggregate of all the* Sines *of the Sun's Altitude, during his appearance above the Horizon; and conſequently of all his Heat and Action on the Plain of the Horizon in the propoſed Day.* And this may alſo be extended to the parts of the ſame Day; for if the aforeſaid Sum of the *Sines* of the Meridian Altitudes, be multiplied by half the ſum of the *Sines* of the Sun's Horary diſtance from Noon, when the Times are before and after Noon; or by half their difference, when both are on the ſame ſide of the Meridian; and thereto in Summer, or therefrom in Winter, be added or ſubſtracted the Product of half the Arch anſwerable to the propoſed interval of Time, into the difference of the *Sines* of Meridian Altitudes, the ſum in one caſe and difference in the other, ſhall be proportional to all the Action of the Sun during that ſpace of time.

I fore-ſee it will be Objected, that I take the *Radius* of my Circle on which I erect my Perpendiculars always the ſame, whereas the Parallels of Declination are unequal; but to this I anſwer, that our ſaid Circular Baſes ought not to be Anologous to the Parallels, but to the Times of Revolution, which are equal in all of them.

It may perhaps be uſeful to give an Example of the Computation of this Rule, which may ſeem difficult to ſome. Let the Solſtitial Heat, in ♋ and ♑ be required at *London*, *Lat.* 51°. 3′2.

380-2′8	*Co-Lat.*		*Diff. Aſcen.* 330:-1′1.
23-30	*Decl.* ⊙		*Arc.Semidi.æſtiv.*123-11.
61-58	*Sinus*═	,882674	*Arc.Semi.hyb.*56-49.*S.*638923
14-58	*Sinus*═	,258257	*Arc.æſtiv.menſ.*2,149955
	Summa	1,140931	*Arc.hyb. menſura* 991683
	Diff.	,624417	

Then 1, 140931 in ,836923+, 624417 in 2, 149955=2, 29734. And 1, 140931 in 836929 ---,624417 in ,991638= 33895.

So that 2, 29734 will be as the Tropical Summers Days Heat, and 0, 33895 as the Action of the Sun in the Day of the Winter Solſtice.

After this manner I computed the following Table for every tenth Degree of Latitude, to the Æquinoctial and Tropical Sun, by which an Eſtimate may be made of the intermediate Degrees.

Lat.	Sun in ♈ ♎	Sun in ♋	Sun in ♑
0	20000	18341	18341
10	19696	20290	15834
20	18794	21737	13166
30	17321	22651	10124
40	15321	23048	6944
50	12855	22991	3798
60	10000	22773	1075
70	6840	23543	000
80	3473	24673	000
90	0000	25055	000

Thoſe that deſire more of the Nature of this Problem, as to the Geometry thereof, would do well to compare the XIII. *Prop. Cap.* V. of the Learned Treatiſe, *De Calculo Centri Gravitatis*, by the Reverend Dr. *Wallis*, Publiſhed *Anno*. 1670.

From this Rule there follow ſeveral Corollaries worth Note: As I. That the Æquinoctial Heat, when the Sun comes Vertical, is as twice the Square of *Radius*, which may be propoſed as a Standard to compare with in all other Caſes. II. That under the Æquinoctial, the Heat is as the *Sine* of the Sun's Declination. III, That in the Frigid Zones when the Sun ſets not, the Heat is as the Circumference of a Circle into the *Sine* of the Altitude at 6. And conſequently, that in the ſame Latitude theſe Aggregates of Warmth, are as the *Sines* of the Sun's Declinations ; and in the ſame Declination of *Sol*, they are as the *Sines* of the Lat., and generally they are as the *Sines* of the Lat. into the *Sines* of Declination. IV. That the Æquinoctial Days Heat is every where as the Co-ſine of the Latitude. V. In all places where the Sun ſets, the difference between the Summer and Winter Heats, when the Declinations are contrary, is equal to a Circle into the *Sine* of the Altitude at ſix in the Summer Parallel, and conſequently thoſe differences are as the *Sines* of Latitude into, or multiplied by the *Sines* of Declination. VI. From the Table I have added, it appears, that the Tropical Sun under the Æquinoctial, has, of all others, the leaſt Force. Under the Pole it is greater than any other Days Heat whatſoever, being to that of the Æquinoctial as 5 to 4.

From the Table and theſe Coralleries may a general *Indea* be conceived of the ſum of all the Actions of the Sun in the whole Year, and that part of the Heat that ariſes ſimply from the Preſence of the Sun be brought to a Geometrical Certainty : And if the like could be performed for Cold ; which is ſomething elſe than the bare Abſence of the Sun, as appears by many Inſtances, we might hope to bring what relates to this part of *Meteorology* to a perfect Theory.

Concerning the Diſtance of the fix'd Stars. By the Honourable Francis Roberts, *Eſq; S.R.S.*

THE Ancient Aſtronomers, who had no other way of computing the Diſtances of the Heavenly Bodies, but by their Parallax to the Semi-diameter of the Earth; and being never able to diſcover any in the fix'd Stars, did from thence rightly enough infer, that their Diſtance was very great, and much exceeding that of the Planets, but could go no farther otherwiſe than by uncertain gueſs.

Since the *Pythagorean* Syſtem of the World has been revived by *Copernicus*, (and now by all Mathematicians accepted for the true one) there ſeemed ground to imagine that the Diameter of the Earth's Annual Courſe (which, according to our beſt Aſtronomers, is at leaſt 40000 times bigger than the Semi-diameter of the Earth) might give a ſenſible Parallax to the fix'd Stars, tho' the other could not, and thereby determine their Diſtance more preciſely.

But though we have a Foundation to build on ſo vaſtly exceeding that of the Ancients, there are ſome Conſiderations may make us ſuſpect that even this is not large enough for our purpoſe.

Monſieur *Hugens* (who is very exact in his Aſtronomical Obſervations) tells us, he could never diſcover any viſible Magnitude in the fix'd Stars, though he uſed Glaſſes which magnified the apparent Diameter above 100 times.

Now, ſince in all likelyhood the fix'd Stars are Suns, (perhaps of a different Magnitude) we may as a reaſonable *Medium* preſume they are generally about the bigneſs of our Sun.

Let us then (for Example) ſuppoſe the Dog-Star to be ſo. The Diſtance from us to the Sun being about 100 times the Sun's Diameter (as is demonſtrable from the Sun's Diameter being 32 minutes) it is evident, that the Angle under which the Dog-Star is ſeen in Mr. *Hugens*'s Teleſcope, muſt be near the ſame with the Angle of its Parallax to the Sun's Diſtance, or Semi-diameter of the Earth's Annual Courſe; ſo that the Parallax to the whole Diameter, can be but double ſuch a quantity, as even to Mr. *Hugens*'s nice Obſervation is altogether inſenſible.

The Diſtance therefore of the fixt Stars ſeems hardly within the reach of any of our Methods to determine; but from what has been laid down, we may draw ſome Concluſions that will much illuſtrate the prodigious vaſtneſs of it.

1. That the Diameter of the Earth's Annual Orb (which contains at leaſt 160 millions of miles) is but as a Point in compariſon of it; at leaſt it muſt be above 6000 times the Diſtance of the Sun: For if a Star ſhould appear through the aforeſaid Teleſcope half a

minute broad (which is a pretty ſenſible Magnitude) the true apparent Diameter would not exceed 18 3d minutes, which is leſs than the 6000th part of the apparent Diameter of the Sun, and conſequently the Sun's Diſtance not the 6000th part of the Diſtance of the Star.

2. That could we advance towards the Stars 99 Parts of the whole Diſtance, and have only $\frac{1}{100}$ Part remaining, the Stars would appear little bigger to us than they do here; for they would ſhew no otherwiſe than they do through a Teleſcope, which magnifies an Hundred-fold.

3. That at leaſt Nine Parts in Ten of the Space between us and the fixed Stars, can receive no greater Light from the Sun, or any of the Stars, than what we have from the Stars in a clear Night.

4. That Light takes up more time in travelling from the Stars to us, than we in making a *Weſt-India* Voyage (which is ordinarily performed in ſix Weeks.) That a Sound would not arrive to us from thence in 50000 Years, nor a Cannon-bullet in a much longer time. This is eaſily computed, by allowing (according to Mr. *Newton*) Ten minutes for the Journey of Light from the Sun hither, and that a Sound moves about 1300 Foot in a Second.

The Famous Mr. Iſaac Newton's *Theory of the* Moon.

THIS *Theory* which hath been long expected by all the true Lovers of *Aſtronomy*, was communicated from Mr. *Newton*, to Dr. *Gregory Aſtron.* Profeſſor at *Oxford*, and by him publiſhed in his *Aſtron. Elem. Philoſ.* and *Geomet.* p. 336. From whence, as it was lately tranſlated into *Engliſh*, I thought fit to inſert it here.

By this Theory, what by all Aſtronomers was thought moſt difficult and almoſt impoſſible to be done, the Excellent Mr. *Newton* hath now effected; *viz.* to determine the Moon's Place even in her Quadratures, and all other Parts of her Orbit, beſides the Syzygys, ſo accurately by Calculation, that the Difference between that and her true Place in the Heavens, ſhall ſcarce be two minutes, and is uſually ſo ſmall, that it may well enough be reckon'd only as a Defect in the Obſervation. And this Mr. *Newton* experienced by comparing it with very many Places of the Moon, obſerv'd by Mr. *Flamſteed*, and communicated to him.

The Royal Obſervatory at *Greenwich*, is to the Weſt of the Meridian of *Paris*, 2 deg. 19 min. Of *Urainburgh*, 12 deg. 51 min. 30 ſeconds. And of *Gedanum*, 18 deg. 48 minutes.

The mean Motions of the Sun and Moon, accounted from the Vernal Æquinox at the Meridian of *Greenwich*, I make to be as followeth.

The laſt Day of *December* 1680, at Noon, (*Old Stile*) the mean Motion of the Sun was 9 Sign, 20 deg. 34 min. 46 ſeconds. Of the Sun's Apogeum, was 3 S. 7 deg. 23 min. 30 ſec.

The mean Motion of the Moon at that time, was 6 S. 1 deg. 35 min. 45 ſeconds. And of her Apogee, 8 S. 4 deg. 28 min. 5 ſeconds. Of the aſcending Node of the Moon's Orbit, 5 S. 24 deg. 14 min. 35 ſeconds, *&c.*

And on the laſt Day of *December*, 1700. at Noon, the mean Motion of the Sun was 9 S. 20 deg. 43 min. 50 ſeconds. Of the Sun's Apogee, 3 S. 7 deg. 44 min. 30 ſeconds. The mean Motion of the Moon was 10 S. 15 deg. 19 min. 50 ſeconds. Of the Moon's Apogee, 11 S. 8 deg. 18 min. 20 ſeconds. And of her aſcending Node, 4 S. 27 deg. 24 min. 20 ſeconds. For in 20 *Julian* Years, or 7305 Days, the Sun's Motion is 20 Revolut. 0 S. 0 deg. 9 min. 4 ſeconds. And the Motion of the Sun's Apogee, 21 min. 0 ſeconds.

The Motion of the Moon in the ſame time, is 247 Revolut. 4 S. 13 deg. 34 min. 5 ſeconds. And the Motion of the Lunar Apogee, is 2 Revolut. 3 S. 3 deg. 50 min. 15 ſeconds. And the Motion of her Node, 1 Revolut. 0 S. 26 deg. 50 min. 15 ſeconds.

All which Motions are accounted from the Vernal Æquinox: Wherefore if from them there be ſubtracted the Receſſion or Motion of the Æquinoctial Point, *in Antecedentia*, during that ſpace, which is 16 min. 0 ſec. there will remain the Motions in reference to the fix'd Stars in 20 *Julian* Years; *viz.* the Sun's 19 Revol. 11 S. 29 deg. 52 min. 24 ſeconds. Of his Apogee, 4 min. 20 ſeconds. And the Moon's 247 Revol. 4 S. 13 deg. 17 min. 25 ſeconds. Of her Apogee, 2 Revol. 3 S. 3 deg. 33 min. 35 ſeconds. And of the Node of the Moon, 1 Revol. 0 S. 27 deg. 6 min. 55 ſeconds.

According to this Computation, the *Tropical Year* is 365 Days, 5 Hours, 48 Minutes, 57 Seconds. And the *Sydereal Year* is 365 Days, 6 Hours, 9 Minutes, 14 Seconds.

Theſe mean Motions of the Luminaries are affected with various Inequalities: Of which,

1. There are the Annual Equations of the aforeſaid mean Motions of the Sun and Moon, and of the Apogee and Node of the Moon.

The Annual Equation of the mean Motion of the Sun, depends on the Eccentricity of the Earth's Orbit round the Sun, which is $16\frac{11}{12}$ of ſuch Parts, as that the Earth's mean Diſtance from the Sun ſhall be 1000: Whence 'tis called the *Equation of the Centre*; and is, when greateſt, 1 deg. 56 min. 20 ſeconds.

The greateſt Annual Equation of the Moon's mean Motion, is 11 deg. 49 ſeconds; of her Apogee, 20 min. and of her Node, 9 minutes, 30 ſeconds.

And theſe four Annual Equations are always mutually proportional one to another: Wherefore when any of them is at the greateſt, the other three will alſo be greateſt; and when any one leſſens, the other three will alſo be diminiſhed in the ſame *Ratio*.

The Annual Equation of the Sun's Centre being given, the three other correſpending Annual Equations will be alſo given; and therefore a Table of that will ſerve for all. For if the Annual Equation of the Sun's Centre be taken from thence, for any Time, and be called P, and let $\frac{1}{10} P = Q$, $Q + \frac{1}{60} Q = R$, $\frac{1}{6} P = D$, $D + \frac{1}{30} D = E$, and $D - \frac{1}{30} D = 2 F$; then ſhall the Annual Equation of the Moon's mean Motion for that time be R, that of the Apogee of the Moon will be E, and that of the Node F.

Only obſerve here, That if the Equation of the Sun's Centre be required to be added; then the Equation of the Moon's mean Motion muſt be ſubtracted, that of her Apogee muſt be added, and that of the Node ſubducted. And on the contrary, if the Equation of the Sun's Centre were to be ſubducted, the Moon's Equation muſt be added, the Equation of her Apogee ſubducted, and that of her Node added.

There is alſo an *Equation of the Moon's mean Motion*, depending on the Situation of her Apogee, in reſpect of the Sun; which is greateſt when the Moon's Apogee is in an Octant with the Sun, and is nothing at all when it is in the Quadratures or Syzygys. This Equation, when greateſt, and the Sun in *Perigæo*, is 3 min. 56 ſeconds. But if the Sun be in *Apogæo*, it will never be above 3 minutes 34 ſeconds. At other Diſtances of the Sun from the Earth, this Equation, when greateſt, is reciprocally as the Cube of ſuch Diſtance. But when the Moon's Apogee is any where but in the *Octants*, this Equation grows leſs, and is moſtly at the ſame diſtance between the Earth and Sun, as the Sine of the double Diſtance of the Moon's Apogee, from the next Quadrature or Syzygy, to the Radius.

This is to be added to the Moon's Motion, while her Apogee paſſes from a Quadrature with the Sun to a Syzygy; but this is to be ſubtracted from it, while the Apogee moves from the Syzygy to the Quadrature.

There is moreover another *Equation of the Moon's Motion*, which depends on the Aſpect of the Nodes of the Moon's Orbit with the Sun: And this is greateſt, when her Nodes are in *Octants* to the Sun, and vaniſhes quite, when they come to their Quadratures or Syzygys. This Equation is proportional to the Sine of the double Diſtance of the Node from the next Syzygy, or Quadrature; and at greateſt, is but 47 ſeconds. This muſt be added to the Moon's mean Motion, while the Nodes are paſſing from their Syzygys with the Sun, to their Quadratures with him; but ſubtracted while they paſs from the Quadratures to the Syzygys.

From the Sun's true Place, take the equated mean Motion of the Lunar Apogee, as was above ſhew'd, the Remainder will be the Annual Argument of the ſaid Apogee. From whence the *Eccentricity of the Moon*, and the *ſecond Equation* of her Apogee may be compar'd after the manner following (*which takes place alſo in the Computation of any other intermediate Equations.*

Let

Tab.3.Fig.6. Let T repreſent the Earth, T S a Right Line joining the Earth and Sun, T A C B a Right Line drawn from the Earth to the middle or mean Place of the Moon's Apogee, equated, as above: Let the Angle S T A be the Annual Argument of the aforeſaid Apogee, T A the leaſt Eccentricity of the Moon's Orbit, T B the greateſt. Biſſect A B in G; and on the Centre C, with the Diſtance A C deſcribe a Circle A F B, and make the Angle B C F =to the double of the Annual Argument. Draw the Right Line T F, that ſhall be the Eccentricity of the Moon's Orbit; and the Angle B T F, is the ſecond Equation of the Moon's Apogee required.

In order to whoſe Determination, let the mean Diſtance of the Earth from the Moon, or the Semi-diameter of the Moon's Orbit, be 1000000; then ſhall its greateſt Eccentricity T B be 66782 ſuch Parts; and the leaſt T A, 43319. So that the greateſt Equation of the Orbit, *viz.* when the Apogee is in the Syzygys, will be 7 deg. 39 min. 30 ſeconds, or perhaps 7 deg. 40 min. (for I ſuſpect there will be ſome Alteration, according to the Poſition of the Apogee in *Cancer* or *Capricorn.)* But when it is Quadrate to the Sun, the greateſt Equation aforeſaid will be 4 deg. 57 min. 56 ſeconds; and the greateſt Equation of the Apogee, 12 deg. 15 min. 4 ſeconds.

Having from theſe Principles made a Table of the Equation of the Moon's Apogee, and of the Eccentricities of her Orbit to each degree of the Annual Argument, from whence the Eccentricity T F, and the Angle B T F (*viz.* the ſecond and principal Equation of the Apogee) may eaſily be had for any Time required; let the Equation thus found be added to the firſt Equated Place of the Moon's Apogee, if the Annual Argument be leſs than 90 degrees, or greater than 180 degrees, and leſs than 270; otherwiſe it muſt be ſubducted from it; and the Summ or Difference ſhall be the Place of the Lunar Apogee ſecondarily equated; which being taken from the Moon's Place equated a third time, ſhall leave the mean Anomaly of the Moon correſponding to any given Time. Moreover, from this mean Anomaly of the Moon, and the before-found Eccentricity of her Orbit, may be found (by means of a Table of Equations of the Moons Centre made to every degree of the mean Anomaly, and ſome Eccentricities, (*viz.* 45000, 50000, 55000, 60000, and 65000) the *Proſtaphæreſis*, or Equation of the Moon's Centre, as in the common way: And this being taken from the former Semi-circle of the middle Anomaly, and added in the latter to the Moon's Place thus thrice equated, will produce the Place of the Moon a fourth time equated.

The greateſt Variation of the Moon (*viz.* that which happens when the Moon is in an Octant with the Sun) is nearly, reciprocally as the Cube of the Diſtance of the Sun from the Earth. Let that be taken 37 min. 25 ſeconds, when the Sun is *in Perigæo*, and 33 min. 40 ſeconds, when he is *in Apogæo*: And let the Differences of this Variation in the Octants be made reciprocally, as the Cubes of the Diſtances of the Sun from the Earth; and ſo let a Table be made of the aforeſaid Variation

tion of the Moon in her Octants (or its Logarithms) to every Tenth, Sixth, or Fifth Degree of the mean Anomaly: And for the Variation out of the Octants, make, as Radius to the Sine of the double Diſtance of the Moon from the next Syzygy, or Quadrature : : ſo let the afore-found Variation in the Octant be to the Variation congruous to any other Aſpect; and this added to the Moon's Place before found in the firſt and third Quadrant (accounting from the Sun) or ſubducted from it in the ſecond and fourth, will give the Moon's Place equated a fifth time.

Again, as Radius to the Sine of the Summ of the Diſtances of the Moon from the Sun, and of her Apogee from the Sun's Apogee (or the Sine of the Exceſs of that Summ above 360 deg.) : : ſo is 2 min. 10 ſeconds, to a ſixth Equation of the Moon's Place, which muſt be ſubtracted, if the aforeſaid Summ or Exceſs be leſs than a Semi-circle; but added, if it be greater. Let it be made alſo, as Radius to the Sine of the Moon's diſtance from the Sun : : ſo 2 deg. 20 ſecants, to a ſeventh Equation; which when the Moon's Light is increaſing, add; but when decreaſing, ſubtract; and the Moon's Place will be equated a ſeventh time, and this is her Place *in her proper Orbit*.

Not here, the Equation thus produced by the mean Quantity 2 degrees, 20 ſeconds, is not always of the ſame magnitude; but is increaſed and diminiſhed, according to the Poſition of the Lunar Apogee. For if the Moon's Apogee be in Conjunction with the

Sun's, the aforeſaid Equation is about 54. ſeconds greater: But when the Apogees are in oppoſition, 'tis about as much leſs; and it librates between its greateſt Quantity 3 minutes, 14 ſeconds, and its leaſt, 1 minute, 26 ſeconds. And this is, when the Lunar Apogee is in Conjunction, or Oppoſition with the Sun's: But in the Quadratures, the aforeſaid Equation is to be leſſen'd about 50 ſeconds, or one minute, when the Apogees of the Sun and Moon are in Conjunction; but if they are in Oppoſition, for want of a ſufficient number of Obſervations, I cannot determine, whether it is to be leſſen'd or increas'd. And even as to the Argument or Decrement of the Equation, 2 minutes, 20 ſeconds, above mentioned, I dare determine nothing certain, for the ſame Reaſon, *viz.* the want of Obſervation accurately made.

If the ſixth and ſeventh Equations are augmented or diminiſhed in a reciprocal *Ratio* of the diſtance of the Moon from the Earth; *i. e.* in a direct *Ratio* of the Moon's Horizontal Parallax, they will become more accurate: And this may be readily done, if Tables are firſt made to each minute of the ſaid Parallax, and to every ſixth or fifth degree of the Argument of the ſixth Equation for the Sixth, as of the diſtance of the Moon from the Sun, for the Seventh Equation.

From the Sun's Place, take the mean motion of the Moon's aſcending Node, equated as above; the Remainder ſhall be the Annual Argument of the Node, whence its ſecond Equation may be computed after the following manner in the preceding Figure.

Let T, as before, repreſent the Earth; TS a Right Line, conjoining the Earth and Sun: Let alſo the Line T A C B, be drawn to the Place of the aſcending Node of the Moon, as above equated; and let STA be the Annual Argument of the Node. Take TA from a Scale, and let it be to A B : : as 56 to 3, or as 11 ⅔ to 1. Then biſſect B A in C, and on C as a Centre, with the Diſtance C A, deſcribe a Circle as A F B, and make the Angle B C F, equal to double the Annual Argument of the Node before-found: So ſhall the Angle B T F, be the ſecond Equation of the aſcending Node; which muſt be added, when the Node is paſſing from the Quadrature to a Syzygy with the Sun; and ſubducted, when the Node moves from a Syzygy towards a Quadrature. By which means, the true Place of the Node of the Lunar Orbit will be gained: Whence from Tables made after the common way, the *Moon's Latitude, and the Reduction of her Orbit to the Ecliptick*, may be computed, ſuppoſing the Inclination of the Moon's Orbit to the Ecliptick, to be 4 deg. 59 min. 35 ſeconds, when the Nodes are in Quadrature with the Sun; and 5 deg. 17 min. 20 ſeconds, when they are in the Syzygys.

And from the Longitude and Latitude thus found, and the given Obliquity of the Ecliptick, 23 degrees, 29 minutes, to the Right Aſcenſion and Declination of the Moon will be found.

The Horizontal Parallax of the Moon, when ſhe is in the Syzygys, at a mean diſtance from the Earth, I make to be 57 min. 30 ſeconds; and her Horary Motion, 33 min. 32

ſeconds, 32 thirds; and her apparent Diameter 31 min. 30 ſeconds. But in her Quadratures at a mean Diſtance from the Earth, I make the Horizontal Parallax of the Moon to be 59 min. 40 ſeconds, her Horary Motion 32 min. 12 ſeconds, 2 thirds, and her apparent Diameter, 31 min. 3 ſeconds. The Moon in an Octant to the Sun, and at a mean diſtance, hath her Centre diſtant from the Centre of the Earth about 60 $\frac{2}{9}$ of the Earth's Semi-diameters.

The Sun's Horizontal Parallax I make to be 10 ſeconds, and its apparent Diameter at a mean diſtance from the Earth, I make 32 minutes, 15 ſeconds.

The Atmoſphere of the Earth, by diſperſing and refracting the Sun's Light, caſts a Shadow,as if it were an Opake Body, at leaſt to the height of 40 or 50 Geographical Miles (by a Geographical Mile, I mean the ſixtieth part of a Degree of a great Circle, on the Earth's Surface.) This Shadow falling upon the Moon in a Lunar Eclipſe, makes the Earth's Shadow be the larger or broader. And to each Mile of the Earth's Atmoſphere, is correſpondent a Second in the Moon's Disk, ſo that the Semi-diameter of the Earth's Shadow projected upon the Disk of the Moon, is to be increaſed about 50 ſeconds: Or, which is all one, in a Lunar Eclipſe, the Horizontal Parallax of the Moon is to be increaſed in the Ratio of about 70 to 69.

Thus far the Theory of this Incomparable Mathematician. And if we had many Places of the Moon accurately obſerved, eſpecially about her Quadratures, and theſe well compared

Plate 3. pag. 280.

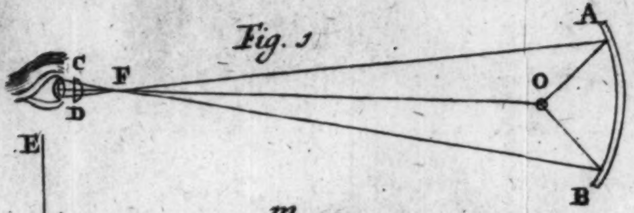


Fig. 1

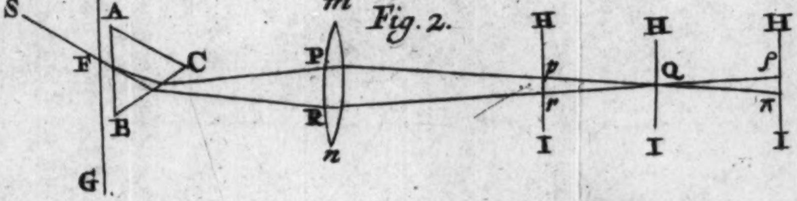


Fig. 2.

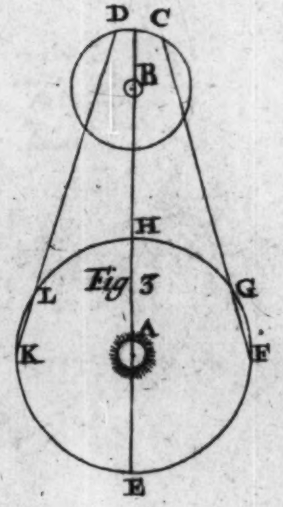


Fig 3

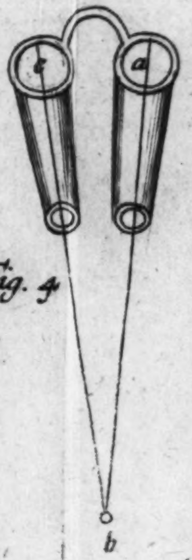
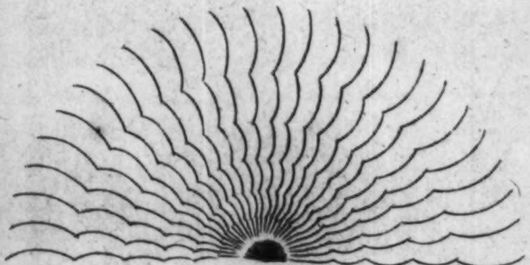


Fig. 4

Fig 5



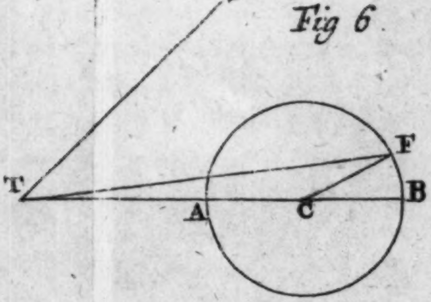


Fig 6

pared with her Places, at the ſame time calculated according to this Theory; it would then appear, whether there yet remain any other ſenſible Equations, which when accounted for, might ſerve to improve and enlarge this Theory.

An Eſtimate of the Degrees of the Mortality *of Mankind, drawn from curious* Tables *of the* Births *and* Funerals *at the City of* Breſlaw; *with an Attempt to aſcertain the Price of* Annuities *upon* Lives. *By Mr.* E. Halley, *R.S.S.*

THE Contemplation of the *Mortality* of *Mankind*, has beſides the *Moral*, its *Phyſical* and *Political* Uſes, both which have been ſome Years ſince moſt judiciouſly conſidered by the curious Sir *William Petty*, in his *Natural* and *Political* Obſervations on the Bills of *Mortality* of *London*, owned by Captain *John Graunt*: And ſince in a like Treatiſe on the Bills of *Mortality* of *Dublin*. But the Deduction from thoſe Bills of *Mortality* ſeemed even to their Authors to be defective: Firſt, In that the *Number* of the People was wanting. Secondly, That the *Ages* of the People dying was not to be had. And Laſtly, That both *London* and *Dublin*, by reaſon of the great and caſual Acceſſion of *Strangers* who die therein, (as appeared in both, by the great Exceſs of the *Funerals* above the *Births*) rendred them incapable of being Standards for this purpoſe; which requires, if it were poſſible, that the People, we treat of, ſhould not at all be changed, but die where they were born, without any adventitious Increaſe from Abroad, or Decay by Migration elſewhere.

This *Defect* ſeems in a great meaſure to be ſatisfied by the late curious Tables of the Bills of *Mortality* at the City of *Breſlaw*, lately communicated to this Honourable Society by Mr. *Juſtell*, wherein both the Ages and Sexes of all that die are monthly delivered, and compared with the number of the *Births*, for Five Years laſt paſt, *viz.* 1687, 88, 89, 90, 91, ſeeming to be done with all the Exactneſs and Sincerity poſſible.

This City of *Breſlaw* is the Capital City of the Province of *Sileſia*; or, as the *Germans* call it, *Schleſia*, and is ſituated on the Weſtern Bank of the River *Oder*, anciently called *Viadrus*, near the Confines of *Germany* and *Poland*, and very nigh the Latitude of *London*. It is very far from the Sea, and as much a *Mediterranean* Place as can be deſired, whence the Confluence of Strangers is but ſmall, and the Manufacture of Linnen employs chiefly the poor People of the Place, as well as of the Country round about; whence comes that ſort of Linnen we uſually call your *Scleſie Linnen*; which is the chief, if not the only Merchandize of the Place. For theſe Reaſons, the People of this City ſeem moſt proper for a *Standard*; and the rather, for that the *Births* do, a ſmall matter exceed the Funerals. The only thing wanting, is the Number of the whole People, which in ſome meaſure I have endeavour'd to ſupply, by the compariſon of the *Mortality* of the People of all Ages, which I ſhall from the ſaid Bills trace out with all the Accuracy poſſible.

It appears that in the Five Years mentioned, *viz.* from 87 to 91 incluſive, there were *born* 6193 Perſons, and buried 5869; that is, born *per Annum* 1238, and *buried* 1174; whence an *Increaſe* of the People may be argued of 64 *per Annum*, or of about a 20th part, which may perhaps be balanced by the Levies for the *Emperor*'s Service in his Wars. But this being contingent, and the Births certain, I will ſuppoſe the People of *Breſlaw* to to be increaſed by 1238 *Births* annually. Of theſe it appears by the ſame Tables, that 348 do die *yearly* in the *firſt Year* of their *Age*, and that but 890 do arrive at a full *Year's Age*; and likewiſe, that 198 do die in the *Five Years* between 1 and 6 compleat, taken at a *Medium*; ſo that but 692 of the Perſons *born* do ſurvive *Six* whole *Years*. From this *Age* the Infants being arrived at ſome degree of Firmneſs, grow leſs and leſs *Mortal*; and it appears, that of the whole People of *Breſlaw* there die *yearly*, as in the following Table, wherein the upper Line ſhews the *Age*, and the next under it, the *Number* of Perſons of that Age *dying yearly*.

7. 8 9. . 14 . 18 . 21 . 27 . 28 . . 35.
11. 11. 6. $5\frac{1}{2}$. 2. $3\frac{1}{2}$ 5 6 $4\frac{1}{2}$ $6\frac{1}{2}$ 9 . 8 . 7 . 7.

36. 42. 45 39 54 . 55 . 56 . . 63
8. $9\frac{1}{2}$ 8 . 9. 7. 7. 10 11 . 9 . 9 . 10 . 12

70 71 . 72 77 81 84 . 90 91.
$9\frac{1}{2}$ 14 9 . 11 $9\frac{1}{2}$ 6 . 7 . 3 . 4 . 2 . 1. 1. 1.

98 . 99 . 100.
0 . $\frac{1}{5}$. $\frac{3}{5}$

And where no Figure is placed over, it is to be underſtood of thoſe that die between the Ages of the precedent and conſequent *Column.*

From this Table it is evident, that from the Age of 9 to about 25, there does not die above 6 *per Annum* of each Age, which is much about 1 *per Cent.* of thoſe that are of thoſe *Ages:* And whereas in the 14, 15, 16, 17 *Years*, there appear to die much fewer, as 2 and $3\frac{1}{2}$; yet that ſeems rather to be attributed to Chance, as are the other Irregularities in the Series of Ages, which would rectifie themſelves, were the number of Years much more conſiderable, as 20 inſtead of 5. And by our own Experience in *Chriſt-Church Hoſpital*, I am informed there die of the *Young Lads*, much about 1 *per Cent. per Annum*, they being of the aforeſaid *Ages.* From 25 to 50, there ſeem to die from 7 to 8 and 9 *per Annum* of each Age; and after that to 70, they growing more *craſie*, though the number be much diminiſhed, yet the *Mortality increaſes*, and there are found to die 10 or 11 of each Age *per Annum*: From thence the number of the Living being grown very ſmall, they gradually decline till there be none left to *die*; as may be ſeen at one View in the Table.

From theſe Conſiderations I have formed the *adjoined Table*, whoſe Uſes are manifold, and give a more juſt *Idea* of the *State* and *Condition* of *Mankind*, than any thing yet extant that I know of. It exhibits the *Number* of *People* in the City of *Breſlaw* of all Ages, from the *Birth* to extreme *Old Age*, and thereby ſhews the Chances of *Mortality* at all *Ages*, and likewiſe how to make a certain Eſtimate of the Value of *Annuities* for *Lives*, which hitherto has been only done by an imaginary *Valuation*: Alſo the *Chances* that there are that a *Perſon* of any *Age* propoſed does live to any other *Age* given; with many more, as I ſhall hereafter ſhew. This *Table* does ſhew the *Number* of Perſons that are living in the *Age* current annexed thereto, as follows:

Age. Curt.	Per- ſons.	Age. Curt.	Per- ſons.	Age. Curt.	Per- ſons.	Age. Curt.	Per- ſons.	Age. Curt.	Per- ſons.	Age. Curt.	Per- ſons.
1	1000	8	680	15	628	22	586	29	539	36	481
2	855	9	670	16	622	23	579	30	531	37	472
3	798	10	661	17	616	24	573	31	523	38	463
4	760	11	653	18	610	25	567	32	515	39	454
5	732	12	646	19	604	26	560	33	507	40	445
6	710	13	640	20	598	27	553	34	499	41	436
7	692	14	634	21	592	28	546	35	490	42	427
Age. Curt.	Per- ſons.	Age. Curt.	Per- ſons.	Age. Curt.	ſons. Per-	Age. Curt.	Per- ſons.	Age. Curt.	Per- ſons.	Age. Curt.	Per- ſons.
43	417	50	346	57	272	64	202	71	131	78	58
44	407	51	335	58	262	65	192	72	120	79	49
45	397	52	324	59	252	66	182	73	109	80	41
46	387	53	313	60	242	67	172	74	98	81	34
47	377	54	302	61	232	68	162	75	88	82	28
48	367	55	292	62	222	69	152	76	78	83	23
49	357	56	282	63	212	70	142	77	68	84	20

Age.	Perſons.
7	5547
14	4584
21	4270
28	3964
35	3604
42	3178
49	2709
56	2194
63	1694
70	1204
77	692
84	253
100	107
	34000
Sum Total.	

Thus it appears, that the whole People of *Breſlaw* does conſiſt of 34000 *Souls*, being the Sum *Total* of the Perſons of all Ages in the *Table*: The firſt uſe hereof is to ſhew the Proportion of *Men* able to bear *Arms* in any *Multitude*, which are thoſe between 18 and 56, rather than 16 and 60; the one being generally too weak to bear the *Fatigues* of *War*, and the Weight of *Arms*; and the other too craſie and infirm from *Age*, notwithſtanding particular Inſtances to the contrary. Under 18 from the *Table*, are found in this City 11997 Perſons, and 3950 above 56, which together make 15947. So that the Reſidue to 34000 being 18053, are Perſons between thoſe *Ages*. At leaſt one half thereof are Males, or 9027: So that the whole Force this City can raiſe of *Fencible Men*, as the *Scotch* call them, is about 9000, or $\frac{9}{34}$, or ſomewhat more than a quarter of the *Number* of *Souls*, which may perhaps paſs for a Rule for all other places.

The *Second Uſe* of this *Table*, is, to ſhew the differing degrees of *Mortality*, or rather *Vitality* in all *Ages*; for if the number of Perſons of any *Age* remaining after one Year, be divided by the difference between that and the number of the Age propoſed, it ſhews the *odds* that there is, that a Perſon of that Age does not die in a *Year*. As for Inſtance, a Perſon of 25 *Years* of *Age* has the odds of 560 to 7, or 80 to 1, that he does not *die* in a *Year*: Becauſe that of 567, living of 25 Years of Age, there do die no more than 7 in a *Year*, leaving 560 of 26 Years old.

So likewiſe for the *odds*, that any Perſon does not die before he attain any propoſed *Age*: Take the *number* of the remaining Perſons of the Age propoſed, and divide it by the difference between it and the number of thoſe of the *Age* of the Party propoſed; and that ſhews the *odds* there is between the Chances of the Party's living or dying. As for Inſtance; What is the *odds* that a Man of 40 lives 7 Years: Take the number of Perſons of 47 Years, which in the Table is 377, and ſubtract it from the number of Perſons of 40 Years, which is 445, and the *difference* is 68: Which ſhews that the *Perſons dying* in that 7 Years, are 68; and that it is 377 to 68, or 5½ to 1, that a Man of 40 does live 7 Years. And the like for any other *number* of *Years*.

Uſe III. But if it be enquired at what number of *Years*, it is an even Lay that a Perſon of any Age ſhall die, this Table readily performs it: For if the *number* of Perſons *living* of the *Age* propoſed, be *halfed*, it will be found by the *Table* at what Year the ſaid *Number* is reduced to half by *Mortality*; and that is the Age, to which it is an even Wager, that a Perſon of the *Age* propoſed ſhall arrive before he *die*. As for Inſtance; A Perſon of 30 Years of Age is propoſed, the number of that Age is 531, the half thereof is 265, which number I find to be between 57 and 58 Years; ſo that a Man of 30 may reaſonably expect to live between 27 and 28 Years.

Uſe IV. By what has been ſaid, the *Price* of *Inſurance* upon Lives ought to be regulated, and the difference is diſcovered between the

Price of inſuring the *Life* of a *Man* of 20 and 50. For Example; it being 100 to 1, that a Man of 20 dies not in a Year, and but 38 to 1, for a Man of 50 Years of Age.

Uſe V. On this depends the Valuation of *Annuities* upon *Lives*; for it is plain, that the *Purchaſer* ought to pay for only ſuch a part of the Value of the *Annuity*, as he has Chances that he is living; and this ought to be computed yearly, and the Sum of all thoſe yearly Values being added together, will amount to the Value of the *Annuity* for the *Life* of the Perſon propoſed. Now the preſent Value of Money payable after a Term of Years, at any given Rate of Intereſt, either may be had from Tables already computed; or almoſt as compendiouſly, by the Table of Logarithms: For the Arithmetical Complement of the Logarithm of Unity and its yearly Intereſt, (that is, of 1, 06 for Six *per Cent.* being 9, 974694.) being multiplied by the number of Years propoſed, gives the preſent Value of One Pound payable after the end of ſo many Years. Then by the foregoing Propoſition, it will be as the number of Perſons living after that Term of Years, to the number dead; ſo are the odds that any one Perſon is alive or dead. And by conſequence, as the Sum of both, or the number of Perſons living of the Age firſt propoſed, to the number remaining after ſo many Years, (both given by the Table) ſo the preſent Value of the yearly Sum payable after the Term propoſed, to the Sum which ought to be paid for the Chance the Perſon has to enjoy ſuch an Annuity after ſo many Years. And this being repeated for every Year of the Perſon's Life, the Sum of all the preſent Values of thoſe Chances is the true Value of the Annuity. This will without doubt appear to be a moſt laborious Calculation; but it being one of the principal Uſes of this Speculation, and having found ſome *Compendia* for the Work, I took the pains to compute the following Table, being the ſhort Reſult of a not ordinary number of Arithmetical Operations: It ſhews the Value of Annuities for every Fifth Year of Age, to the Seventieth, as follows.

Age	Years Pur.	Age	Years Pur.	Age	Years Pur.
1	10,28	25	12,27	50	9,21
5	13,40	30	11,72	55	8,51
10	13,44	35	11,12	60	7,60
15	13,33	40	10,57	65	6,54
20	12,78	45	9,91	70	5,32

This ſhews the great Advantage of putting Money into the preſent *Fund* lately granted to Their Majeſties, giving 14 *per Cent. per Annum*, or at the Rate of 7 Years Purchaſe for a Life; when young Lives, at the uſual Rate of Intereſt, are worth above 13 Years Purchaſe. It ſhews likewiſe the Advantage of young Lives over thoſe in Years; a Life of Ten Years being almoſt worth 13½ Years Purchaſe, whereas one of 36 is worth but 11.

Uſe V. Two Lives are likewiſe valuable by the ſame Rule; for the number of Chances of each ſingle Life, found in the Table, being multiplied together, become the Chances of the Two Lives. And after any certain

Term of Years, the Product of the two remaining Sums is the Chances that both the Perſons are living. The Product of the two Differences, being the numbers of the Dead of both Ages, are the Chances that both the Perſons are dead. And the two Products of the remaining Sums of the one Age multiplied by thoſe dead of the other, ſhew the Chances that there are, that each Party ſurvives the other: Whence is derived the Rule to eſtimate the Value of the Remainder of one Life after another. Now as the Product of the Two Numbers in the Table for the Two Ages propoſed, is to the difference between that Product, and the Product of the two numbers of Perſons deceaſed in any ſpace of time; ſo is the Value of a Sum of Money to be paid after ſo much time, to the Value thereof under the Contingency of Mortality. And as the aforeſaid Product of the two Numbers anſwering to the Ages propoſed, to the Product of the Deceaſed of one Age multiplied by thoſe remaining alive of the other; ſo the Value of a Sum of Money to be paid after any time propoſed, to the Value of the Chances, that the one Party has that he ſurvives the other, whoſe number of Deceaſed you made uſe of, in the ſecond Term of the Proportion. This perhaps may be better underſtood, by putting N for the number of the younger Age, and n for that of the Elder; Y, y the Deceaſed of both Ages reſpectively, and R, r for the Remainders; and $R + Y = N$ and $r + y = n$. Then ſhall Nn be the whole Number of Chances; $Nn - Yy$ be the Chances that one of the two Perſons is living, *Y y* the Chances that they are both dead; *R y* the Chances that the elder Perſon is dead and the younger living; and *r Y* the Chances, that the elder is living and the younger dead. Thus two Perſons of 18 and 35 are propoſed, and after 8 Years theſe Chances are required. The Numbers for 18 and 35, are 610 and 490; and there are 50 of the Firſt Age dead in 8 Years, and 73 of the Elder Age. There are in all 610 x 490, or 298900 Chances; of theſe there are 50 x 73, or 3650, that they are both dead. And as 298900, to 298900 — 3650, or 295250: So is the preſent Value of a Sum of Money to be paid after 8 Years, to the preſent Value of a Sum to be paid, if either of the two live. And as 560 x 73, ſo are the Chances that the Elder is dead leaving the Younger; and as 417 x 50, ſo are the Chances that the Younger is dead, leaving the Elder. Wherefore as 610 x 490 to 560 x 73, ſo is the preſent Value of a Sum to be paid at 8 Years end, to the Sum to be paid for the Chance of the Younger's Survivance; and as 610 x 490 to 417 x 50, ſo is the ſame preſent Value to the Sum to be paid for the Chance of the Elder's Survivance.

This poſſibly may be yet better explained by expounding theſe Products by Rectangular Parallelograms, as in *Fig.* 7. wherein *A B* or *C D* repreſents the number of Perſons of the younger Age, and *D E*, *B H* thoſe remaining alive after a certain Term of Years; whence *C E* will anſwer the number of thoſe dead in that time: So *A C*, *B D* may repreſent the number of the elder Age; *A F*, *B I* the Survivors after the ſame Term; and CF, DI, thoſe of that Age that are dead at that time. Then ſhall the whole Parallelogram $ABCD$ be Nn, or the Product of the two Numbers of Perſons, repreſenting ſuch a number of Perſons of the two Ages given; and by what was ſaid before, after the Term propoſed, the Rectangle HD ſhall be as the number of Perſons of the younger Age that ſurvive, and the Rectangle AE as the number of thoſe that die. So likewiſe the Rectangles AI, FD ſhall be as the Numbers, living and dead, of the other Age. Hence the Rectangle HI ſhall be as an equal number of both Ages ſurviving. The Rectangle FE being the Product of the Deceaſed, or Yy, an equal number of both dead. The Rectangle GD or Ry, a number living of the younger Age, and dead of the elder: And the Rectangle AG or rY a number living of the elder Age, but dead of the younger. This being underſtood, it is obvious, that as the whole Rectangle AD or Nn is to the *Gnomon* $FABDEG$ or $Nn-Yy$, ſo is the whole number of Perſons or Chances, to the number of Chances that one of the two Perſons is living: And as AD or Nn is to FE or Yy, ſo are all the Chances, to the Chances that both are dead; whereby may be computed the Value of the Reverſion after both Lives. And as AD to GD or Ry, ſo the whole number of Chances, to the Chances that the younger is living, and the other dead; whereby may be caſt up what Value ought to be paid for the Reverſion of one Life after another, as in the Caſe of providing for Clergy-mens Widows, and others, by ſuch

Reverſions. And as AD to AG, or rY, ſo are all the Chances, to thoſe that the elder ſurvives the younger. I have been the more particular, and perhaps tedious, in this Matter, becauſe it is the Key to the Caſe of Three Lives, which of it ſelf would not have been ſo eaſie to comprehend.

VII. If Three Lives are propoſed, to find the Value of an Annuity during the continuance of any of thoſe three Lives; the Rule is, *As the Product of the continual Multiplication of the Three Numbers, in the Table, anſwering to the Ages propoſed, is to the difference of that Product, and of the Product of the Three Numbers of the Deceaſed of thoſe Ages, in any given Term of Years: So is the preſent Value of a Sum of Money, to be paid certainly after ſo many Years, to the preſent Value of the ſame Sum to be paid, provided one of thoſe Three Perſons be living at the Expiration of that Term.* Which Proportion being yearly repeated, the Sum of all thoſe preſent Values will be the Value of an Annuity granted for three ſuch Lives. But to explain this, together with all the Caſes of Survivance in Three Lives: Let N be the Number in the Table for the younger Age, n for the ſecond, and ν for the elder Age; let Y be thoſe dead of the younger Age in the Term propoſed, y thoſe dead of the ſecond Age, and υ thoſe of the elder Age; and let R be the Remainder of the younger Age, r that of the middle Age, and ϱ the Remainder of the elder Age. Then ſhall $R + Y$ be equal to N, $r + y$ to n, and $\varrho + \upsilon$ to ν, and the continual Product of the three Numbers $Nn\nu$ ſhall be equal to the continual Product of

$R + \Upsilon \times r + y \times \varrho + \upsilon$, which being the whole Number of Chances for three Lives, is compounded of the eight Products following. (1) $R r \varrho$, which is the Number of Chances that all three of the Perſons are living. (2) $r \varrho \Upsilon$, which is the Number of Chances that the two elder Perſons are living, and the younger dead. (3) $R \varrho y$ the Number of Chances that the middle Age is dead, and the younger and elder living. (4) $R r \upsilon$ being the Chances that the two younger are living, and the elder dead. (5) $\varrho \Upsilon y$ the Chances that the two younger are dead, and the elder living, (6) $r \Upsilon \upsilon$ the Chances that the younger and elder are dead, and the middle Age living. (7) $R y \upsilon$, which are the Chances that the younger is living, and the two other dead. And Laſtly and Eighthly, $\Upsilon y \upsilon$, which are the Chances that all three are dead. Which latter ſubtracted from the whole Number of Chances $N n \nu$, leaves $N n \nu - \Upsilon y \upsilon$ the Sum of all the other ſeven Products; in all of which one or more of the three Perſons are ſurviving.

To make this yet more evident, I have added *Fig.* 8. wherein theſe eight ſeveral Products are at one view exhibited. Let the rectangled Parallelepipedon *ABCDEFGH* be conſtituted of the ſides *AB*, *GH*, *&c.* proportional to *N* the Number of the younger Age; *AC*, *BD*, *&c.* proportional to *n*; and *AG*, *CE*, *&c.* proportional to the Number of the elder, or *ν*. And the whole Parallelepipedon ſhall be as the Product $N n \nu$, or our whole Number of Chances. Let *BP* be as *R*, and *AP* as Υ; let *CL* be as *r*, and *Ln* as y; and GN as ϱ, and NA as υ; and let the Plain $PRea$ be made parallel to the Plain $ACGE$; the Plain $NVbY$ parallel to $ABCD$; and the Plain $LXTQ$ parallel to the Plain $ABGH$. And our firſt Product $Rr\varrho$ ſhall be as the Solid $STWIFZeb$. The Second, or $r\varrho Y$ will be as the Solid $EYZeQSMI$. The Third, $R\varrho y$, as the Solid $RHOVWIST$. And the Fourth, $Rr\upsilon$, as the Solid $ZabDWXIK$. Fifthly, ϱYy, as the Solid $GQRSIMNO$. Sixthly, $rY\upsilon$, as $IKLMGYZA$. Seventhly, $Ry\upsilon$, as the Solid $IKPOBXVW$. And Laſtly, $AIKLMNOP$ will be as the Product of the 3 Numbers of Perſons dead, or $Yy\upsilon$. I ſhall not apply this in all the Caſes thereof for brevity-ſake; only to ſhew in one how all the reſt may be performed, let it be demanded what is the Value of the Reverſion of the younger Life after the two elder propoſed. The Proportion is as the whole Number of Chances, or $Nn\upsilon$ to the Product $Ry\upsilon$; ſo is the certain preſent Value of the Sum payable after any Term propoſed, to the Value due to ſuch Chances as the younger Perſon has to bury both the elder, by the Term propoſed; which thereſore he is to pay for. Here it is to be noted, that the firſt Term of all theſe Proportions is the ſame throughout, *viz.* $Nn\upsilon$. The ſecond changing yearly according to the Decreaſe of R, r, ϱ, and Increaſe of Y, y, υ. And the third are ſucceſſively the preſent Values of Money payable after one, two, three, *&c.* years, according to the Rate of Intereſt agreed on. Theſe Numbers, which are in all Caſes of Annuities of neceſſary Uſe, I have put into the following Table, they being the Decimal Values of one Pound payable after the Number of Years in the Margent, at the Rate of *6 per Cent.*

Years.	Preſ. Value of 1 *l.*	Years.	Preſ. Value of 1 *l.*	Years.	Preſ. Value of 1 *l.*
1	0,9434	19	0,3305	37	0,1158
2	0,8900	20	0,3118	38	0,1092
3	0,8396	21	0,2941	39	0,1031
4	0,7921	22	0,2775	40	0,0972
5	0,7473	23	0,2618	45	0,0726
6	0,7050	24	0,2470	50	0,0543
7	0,6650	25	0,2330	55	0,0406
8	0,6274	26	0,2198	60	0,0303
9	0,5919	27	0,2074	65	0,0227
10	0,5584	28	0,1956	70	0,0169
11	0,5268	29	0,1845	75	0,0126
12	0,4970	30	0,1741	80	0,0094
13	0,4688	31	0,1643	85	0,0071
14	0,4423	32	0,1550	90	0,0053
15	0,4173	33	0,1462	95	0,0039
16	0,3936	34	0,1379	100	0,0029
17	0,3714	35	0,1301		
18	0,3503	36	0,1227		

It were needleſs to advertiſe, that the great trouble of working ſo many Proportions will be very much alleviated by uſing Logarithms; and that inſtead of uſing *N n v—Y y v* for the ſecond Term of the Proportion in finding the Value of Three Lives, it may ſuffice to uſe only *Y y v*, and then deducting the fourth Term ſo found out of the third, the Remainder ſhall be the preſent Value ſought; or all theſe fourth Terms being added together, and deducted out of the Value of the certain Annuity for ſo many Years, will leave the Value of the contingent Annuity upon the Chance of Mortality of all thoſe Three Lives. For Example; Let there be Three Lives of 10, 30, and 40 Years of Age propoſed, and the Proportions will be thus;

As 661 in 531 in 445 or 156190995, or *Nnv*
to 8 in 8 in 9, or 576, or *Yyv* for the firſt Year, ſo 0,9434. to 0,00000348.
To 15 in 16 in 18, or 4320, for the ſecond Year, ſo 0,8900. to 0,00002462.
To 21 in 24 in 28, or 14112 for the third Year, ſo 0,8396. to 0,00008128.
To 27 in 32 in 38, for the fourth Year, ſo 0,7921. to 0,00016650.
To 33 in 41 in 48, for the fifth Year, ſo 0,7473. to 0,00031071.
To 39 in 50 in 58, for the ſixth Year, ſo 0,7050. to 0,00051051.

And ſo forth to the 60th Year, when we ſuppoſe the elder Life of Forty certainly to be expired; from whence 'till Seventy we muſt compute for the Firſt and Second only, and from thence to Ninety for the ſingle youngeſt Life. Then the Sum Total of all theſe Fourth Proportionals being taken out of the Value of a certain Annuity for 90 Years, being 16, 58 Years Purchaſe, ſhall leave the juſt Value to be paid for an Annuity during the whole Term of the Lives of Three Perſons of the Ages propoſed. And note, that it will not be neceſſary to compute for every Year ſingly; but that in moſt Caſes every 4th or 5th Year may ſuffice, interpoling for the intermediate Years *ſecundum artem.*

It may be objected, that the different *Salubrity* of Places does hinder this Propoſal from being *univerſal*; nor can it be denied. But by the Number that die, being 1174. *per Annum* in 34000, it does appear that about a 30th part die yearly, as Sir *William Petty* has computed for *London*; and the Number that die in Infancy, is a good Argument that the Air is but indifferently ſalubrious. So that by what I can learn, there cannot perhaps be one better Place propoſed for a Standard. At leaſt 'tis deſired, that in imitation hereof the Curious in other Cities would attempt ſomething of the ſame Nature, than which nothing perhaps can be more uſeful.

Were this *Calculus* founded on the Experience of a very great number of Years, it would be very well worth the while to think of Methods for facilitating the Computation of the Value of two, three, or more Lives; which, as propoſed in my former, ſeems (as I am inform'd) a Work of too much Difficulty for the ordinary Arithmetician to undertake.

I have ſought, if it were poſſible, to find a Theorem that might be more conciſe than the Rules there laid down, but in vain; for all that can be done to expedite it, is, by Tables of Logarithms ready computed, to exhibit the *Rationes* of *N* to *T* in each ſingle Life, for every third, fourth, or fifth Year of Age, as occaſion ſhall require; and theſe Logarithms being added to the Logarithms of the preſent Value of Money payable after ſo many Years, will give a Series of Numbers, the Sum of which will ſhew the Value of the Annuity ſought. However for each Number of this Series, two Logarithms for a ſingle Life, three for two Lives, and four for three Lives, muſt neceſſarily be added together. If you think the Matter, under the Uncertainties I have mentioned, to deſerve it, I ſhall ſhortly give you ſuch a Table of Logarithms, as I ſpeak of, and an Example or two of the uſe thereof: But by Vulgar Arithmetick, the Labour of theſe Numbers were immenſe; and nothing will more recommend the uſeful Invention of Logarithms to all Lovers of Numbers, than the advantage of Diſpatch in this and ſuch like Computations.

Beſides the Uſes mentioned, it may perhaps not be an unacceptable thing to infer from the ſame Tables, how unjuſtly we repine at the ſhortneſs of our Lives, and think our ſelves wronged if we attain not old Age; whereas it appears hereby, that the one half of thoſe that are born are dead in Seventeen Years time, 1238 being in that time reduced to 616. So that inſtead of murmuring at what we call an untimely Death, we ought with Patience and Unconcern to ſubmit to that Diſſolution which is the neceſſary Condition of our periſhable Materials, and of our nice and frail Structure and Compoſition: And to account it as a Bleſſing that we have ſurvived, perhaps by many Years, that Period of Life, whereat the one half of the whole Race of Mankind does not arrive.

A ſecond Obſervation I make upon the ſaid Table, is that the Growth and Increaſe of Mankind is not ſo much ſtinted by any thing in the Nature of the *Species*, as it is from the cautious difficulty moſt People make to adventure on the State of *Marriage*, from the Proſpect of the Trouble and Charge of providing for a Family. Nor are the poorer ſort of People herein to be blamed, ſince their difficulty of ſubſiſting is occaſion'd by the unequal Diſtribution of Poſſeſſions, all being neceſſarily fed from the Earth, of which yet ſo few are Maſters. So that beſides themſelves and Families, they are yet to work for thoſe who own the Ground that feeds them: And of ſuch does by very much the greater part of Mankind conſiſt; otherwiſe it is plain, that there might well be four times as many Births as we now find. For by Computation from the Table, I find that there are nearly 15000 Perſons above 16 and under 45, of which at leaſt 7000 are Women capable to bear Children. Of theſe notwithſtanding there are but 1238 born yearly, which is but little more than a ſixth part: So that about one in ſix of theſe Women do breed yearly; whereas were they all married, it would not appear ſtrange or unlikely, that four of ſix ſhould bring a Child every Year. The Political Conſequences hereof I ſhall not inſiſt on; only the Strength and Glory of a King being in the multitude of his Subjects, I ſhall only hint, that above all things, Celibacy ought to be diſcouraged, as, by extraordinary Taxing and Military Service: And thoſe who have numerous Families of Children to be countenanced

nanced and encouraged by ſuch Laws as the *Jus trium Liberorum* among the *Romans*. But eſpecially, by an effectual Care to provide for the Subſiſtence of the Poor, by finding them Employments, whereby they may earn their Bread, without being chargeable to the Publick.

A

A Diſcourſe concerning Gravity, *and its Properties, wherein the Deſcent of* Heavy *B*odies, *and the Motion of* Projects *is briefly, but fully handled: Together with the* Solution *of a* Problem *of great Uſe in* Gunnery. *By* E. Halley.

NATURE amidſt the great Variety of *Problems*, wherewith She exerciſes the Wits of Philoſophical Men, ſcarce affords any one wherein the Effect is more viſible, and the Cauſe more concealed, than in thoſe of the *Phænomena* of *Gravity*. Before we can go alone, we muſt learn to defend our ſelves from the violence of its Impulſe, by not truſting the *Center* of *Gravity* of our Bodies beyond our reach; and yet the acuteſt Philoſophers, and the ſubtileſt Enquirers into the Original of this Motion, have been ſo far from ſatisfying their Readers, that they themſelves ſeem little to have underſtood the Conſequences of their own *Hypotheſes.*

Des Cartes his Notion, I muſt needs confeſs to be to me incomprehenſible, while he will have the Particles of his *Celeſtial Matter*, by being reflected on the Surface of the *Earth*, and ſo aſcending therefrom, to drive down into their Places thoſe *Terreſtrial Bodies* they find above them: This is as near as I can gather, the Scope of the 20, 21, 22, and 23 *Sections* of the laſt Book of his *Principia Philoſophiæ*; yet neither he, nor any of his Followers, can ſhew how a Body ſuſpended in *Libero Æthere*, ſhall be carried downwards by a continual Impulſe tending upwards, and acting upon all its Parts equally: And beſides the Obſcurity wherewith he expreſſes himſelf particularly, *Sect.* 23. does ſufficiently argue according to his own Rules, the confuſed *Idea* he had of the thing he wrote.

Others, and among them Dr. *Voſſius*, aſſert the Cauſe of the *Deſcent* of *heavy Bodies*, to be the *Diurnal Rotation* of the *Earth* upon its *Axis*, without conſidering, that according to the Doctrine of Motion fortified with Demonſtration, all Bodies moved *in Circulo*, would recede from the Center of their Motion; whereby the contrary to *Gravity* would follow, and all looſe Bodies would be caſt into the Air in a *Tangent* to the *Parallel* of *Latitude*, without the intervention of ſome other Principle to keep them faſt, ſuch as is that of *Gravity*. Beſides, the Effect of this Principle is throughout the whole Surface of the Globe found nearly equal; and certain Experiments have proved it rather leſs near the *Æquinoctial*, than towards the *Poles*; which could not be by any means, if the *Diurnal Rotation* of the *Earth* upon its *Axis* were the Cauſe of *Gravity*; for where the Motion was ſwifteſt, the Effect would be moſt conſiderable.

Others aſſign the Preſſure of the *Atmoſphere*, to be the Cauſe of this Tendency towards the Center of the Earth; but unhappily they have miſtaken the Cauſe for the Effect; it being from undoubted Principles plain, that the *Atmoſphere* has no other Preſſure but what it derives from its *Gravity*; and that the Weight of the upper Parts of the *Air*, preſſing on the lower Parts thereof, do ſo far bend the Springs of that *Elaſtick* Body, as to give it a Force equal to the Weight that compreſs'd it, having of it ſelf no force at all: And ſuppoſing it had, it will be very hard to explain the *Modus*, how that Preſſure ſhould occaſion the Deſcent of a Body circumſcribed by it, and preſſed equally above and below, without ſome other Force to draw, or thruſt it downwards. But to demonſtrate the contrary of this Opinion, an *Experiment* was long ſince ſhewn before the *Royal Society*, whereby it appeared, that the *Atmoſphere* was ſo far from being the Cauſe of *Gravity*, that the Effects thereof were much more vigorous, where the Preſſure of the *Atmoſphere* was taken off; for a long *Glaſs-Receiver* having a light Down-feather included, being evacuated of Air, the Feather, which in the Air would hardly ſink, did *in vacuo* deſcend with nearly the ſame *Velocity*, as if it had been a Stone.

Some think to illuſtrate this Deſcent of Heavy Bodies, by comparing it with the Vertue of the *Loadſtone*; but ſetting aſide the difference there is in the manner of their Attractions, the *Loadſtone* drawing only in and about its Poles, and the Earth near equally in all Parts of its Surface, this Compariſon avails no more than to explain *ignotum per æque ignotum.*

Others aſſign a certain *Sympathetical Attraction* between the Earth and its Parts, whereby they have, as it were, a deſire to be united, to be the Cauſe we enquire after: But this is ſo far from explaining the *Modus*, that it is little more, than to tell us in other Terms, that Heavy Bodies deſcend, becauſe they deſcend.

This, I ſay, not that I can pretend to ſubſtitute any Solution of this Important Philoſophical Problem, that ſhall more happily explicate the Appearances of Gravity; only it may be ſerviceable to thoſe with whom the Credit of great Authors ſways much, and who too readily aſſent *in Verba Magiſtri*, to let them ſee that their Books are not always infallible: Beſides, the detection of Errors is the firſt and ſureſt Step towards the diſcovery of Truth.

Tho' the efficient Cauſe of *Gravity* be ſo obſcure, yet the final Cauſe thereof is clear enough; for it is by this ſingle *Principle*, that the *Earth* and all the *Celeſtial Bodies* are kept from *Diſſolution*; the leaſt of their *Particles* not being ſuffer'd to recede far from their *Surfaces*, without being immediately brought down again by virtue of this *Natural Tendency*; which, for their Preſervation, the Infinite Wiſdom of their *Creator* has ordained to be towards each of their *Centers*; nor can the *Globes* of the *Sun* and *Planets* otherwiſe be deſtroy'd, but by taking from them this Power of keeping their Parts united.

The Affections or Properties of *Gravity*, and its manner of acting upon *Bodies falling*, have been in a great meaſure diſcovered, and moſt of them made out by *Mathematical Demonſtration* in this our *Century*, by the accurate diligence of *Galilæus*, *Torricellius*, *Hugenius*, and others, and now lately by our worthy Country-man, Mr. *Iſaac Newton*, which Properties it may be very material here to enumerate, that they may ſerve for a Foundation to all thoſe that ſhall be willing to ſpend their Thoughts in ſearch of the true Cauſe of this *Deſcent* of *Bodies.*

The firſt Property is, That by this Principle of *Gravitation*, all Bodies do deſcend towards a Point, which either is, or elſe is very near to the Center of Magnitude of the Earth and Sea, about which the Sea forms it ſelf exactly into a *Spherical Surface*, and the *Prominences* of the Land, conſidering the Bulk of the whole, differ but inſenſibly therefrom.

Secondly, That this Point or Center of *Gravitation*, is fix'd within the *Earth*, or at leaſt has been ſo, ever ſince we have any *Authentick Hiſtory:* For a Conſequence of its Change, tho' never ſo little, would be the over-flowing of the low Lands on that ſide of the *Globe* towards which it approached, and the leaving new Iſlands bare on the oppoſite ſide, from which it receded; but for this Two thouſand Years it appears, that the low Iſlands of the *Mediterranean Sea* (near to which the ancienteſt Writers lived) have continued much at the ſame height above the Water, as they now are found; and no *Inundations* or *Receſſes* of the *Sea* arguing any ſuch Change, are recorded in Hiſtory; excepting the *Univerſal Deluge*, which can no better way be accounted for, than by ſuppoſing this Center of *Gravitation* removed for a time, towards the middle of the then inhabited Parts of the World; and a change of its Place, but the two thouſandth Part of the *Radius* of this *Globe*, were ſufficient to bury the Tops of the higheſt Hills under Water.

Thirdly, That in all Parts of the *Surface* of the *Earth*, or rather in all Points equidiſtant from its *Center*, the Force of *Gravity* is nearly equal; ſo that the length of the *Pendulum* vibrating *Seconds of Time*, is found in all Parts of the World to be very near the ſame. 'Tis true at S. *Helena*, in the *Latitude* of 16 Degrees *South*, I found that the *Pendulum* of my Clock, which vibrated *Seconds*, needed to be made ſhorter than it had been in *England*, by a very ſenſible Space (but which at that time I neglected to obſerve accurately) before it would keep time; and ſince the like Obſervations have been made by the *French Obſervers* near the *Æquinoctial*: Yet I dare not affirm, that in mine it proceeded from any other Cauſe, than the great Heighth of my Place of Obſervation above the *Surface* of the *Sea*, whereby the *Gravity* being diminiſhed, the length of the *Pendulum* vibrating *Seconds*, is proportionably ſhort'ned.

Fourthly, That *Gravity* does equally affect all *Bodies*, without regard either to their *Matter*, *Bulk*, or *Figure*; ſo that the Impediment of the *Medium* being removed, the moſt compact and moſt looſe, the greateſt and ſmalleſt *Bodies* would deſcend the ſame *Spaces* in equal

Times;

Times; the Truth thereof will appear from the Experiment I before cited. In theſe two laſt Particulars, is ſhewn the great difference between *Gravity* and *Magnetiſm*, the one affecting only *Iron*, and that towards its *Poles*, the other all *Bodies* alike in every part. As a *Corollary*, from hence it will follow, that there is no ſuch thing as *poſitive Levity*, thoſe things that appear light, being only comparatively ſo; and whereas ſeveral things riſe and ſwim in *Fluids*, 'tis becauſe, Bulk for Bulk, they are not ſo heavy as thoſe *Fluids*; nor is there any Reaſon why *Cork*, for Inſtance, ſhould be ſaid to be light, becauſe it ſwims on Water, any more than *Iron*, becauſe it ſwims on *Mercury*.

5*ly*, That this Power increaſes as you deſcend, and decreaſes as you aſcend from the Center, and that in the Proportion of the Squares of the *Diſtances* therefrom *reciprocally*, ſo as at a double Diſtance to have but a quarter of the Force; this Property is the Principle on which Mr. *Newton* has made out all the *Phænomena* of the *Celeſtial Motions*, ſo eaſily and naturally, that its Truth is paſt Diſpute. Beſides that, it is higly rational, that the *attractive* or *gravitating* Power ſhould exert it ſelf more vigorouſly in a ſmall Sphere, and weaker in a greater, in proportion as it is contracted or expanded; and if ſo, ſeeing that the *Surfaces* of *Spheres* are as the *Squares* of their *Radii*, this Power, at ſeveral Diſtances, will be as the *Squares* of thoſe *Diſtances reciprocally*; and then its whole Action upon each *Spherical Surface*, be it great or ſmall, will be always equal. And this is evidently the Rule of *Gravitation*

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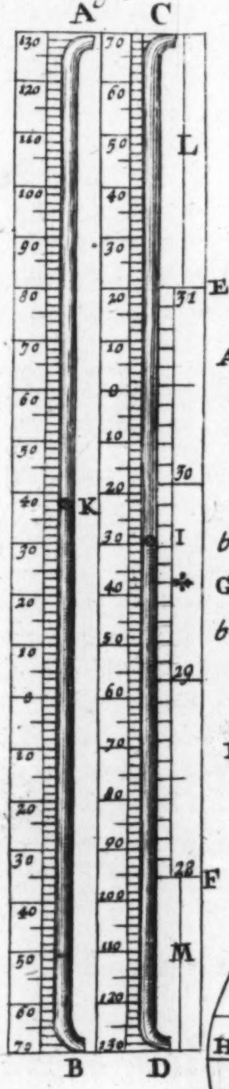
Fig 1



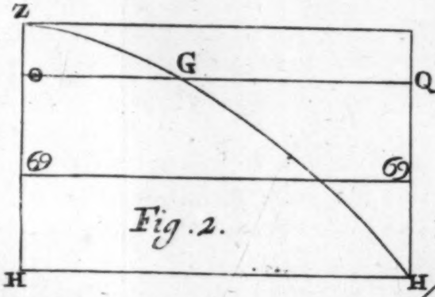


Fig. 2.

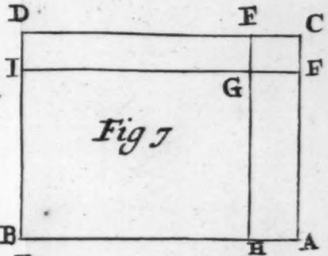
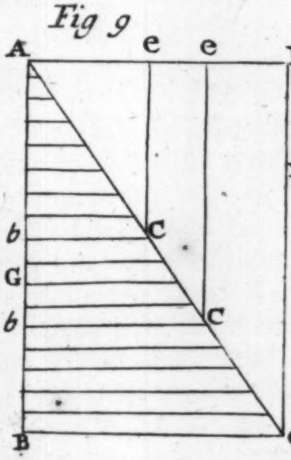


Fig 7

Fig 9



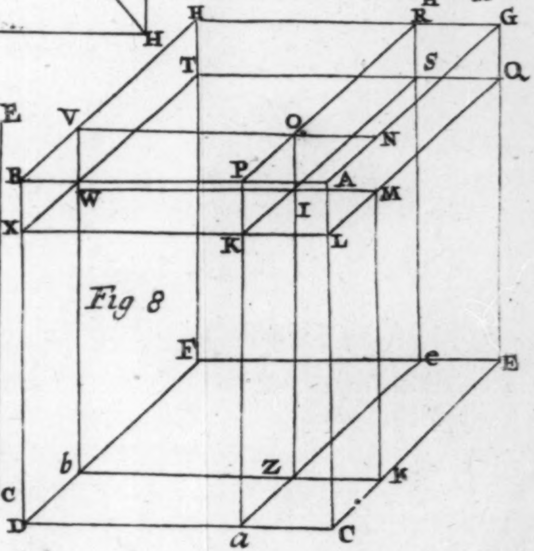
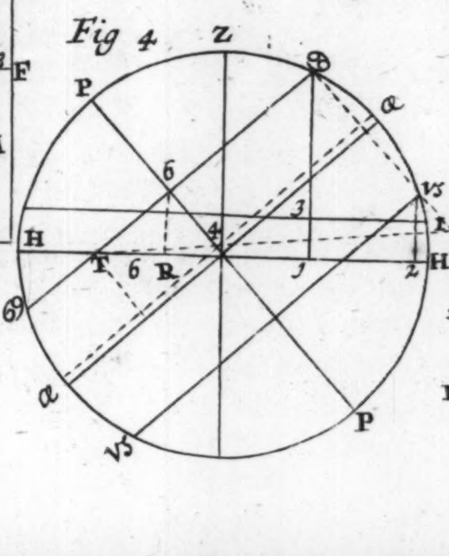


Fig 8

Fig 4



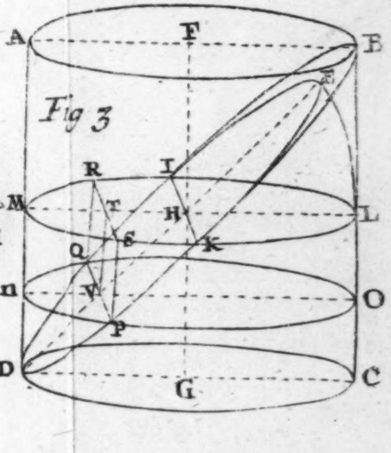


Fig 3

towards the *Centers* of the *Sun*, *Jupiter*, *Saturn* and the *Earth*, and thence is reaſonably inferred, to be the general Principle obſerved by *Nature*, in all the reſt of the *Celeſtial Bodies.*

Theſe are the principal Affections of *Gravity*, from which the Rules of the *Fall* of *Bodies*, and the *Motion* of *Projects* are *Mathematically* deducible. Mr. *Iſaac Newton* has ſhew'd how to define the Spaces of the *Deſcent* of a *Body*, let fall from any given heighth, down to the *Center*, ſuppoſing the *Gravitation* to increaſe, as in the fifth Property; but conſidering the ſmallneſs of heighth, to which any *Project* can be made aſcend, and over how little an *Arch* of the *Globe* it can be caſt by any of our *Engines*, we may well enough ſuppoſe the *Gravity* equal throughout, and the Deſcents of *Projects* in parallel Lines, which in Truth are towards the *Center*, the difference being ſo ſmall as by no means to be diſcovered in *Practice*. The *Oppoſition* of the *Air*, 'tis true, is conſiderable againſt all light Bodies moving through it, as likewiſe againſt ſmall ones (of which more hereafter) but in great and ponderous Shot, this Impediment is found by *Experience* but very ſmall, and may ſafely be neglected.

Propoſitions concerning the Deſcent of Heavy Bodies, and the Motion of Projects.

Prop. I. The *Velocities* of *falling Bodies*, are proportionate to the Times from the beginning of their *Falls*.

This follows, for that the Action of *Gravity* being *continual*, in every Space of Time, the falling Body receives a new Impulſe, equal to what it had before, in the ſame Space of Time, received from the ſame Power: For Inſtance, in the firſt Second of Time, the falling Body has acquired a *Velocity*, which in that time would carry it to a certain Diſtance, ſuppoſe 32 Foot, and were there no new Force, would deſcend at that rate with an *equable Motion*: But in the next Second of Time, the ſame Power of *Gravity* continually acting thereon, ſuperadds a new *Velocity* equal to the former; ſo that at the end of two Seconds, the *Velocity* is double to what it was at the end of the firſt, and after the ſame manner may it be proved to be triple, at the end of the third Second, and ſo on. Wherefore the *Velocities* of *falling Bodies*, are proportionate to the Times of their *Falls*, *Q. E. D.*

Prop. II. The *Spaces* deſcribed by the Fall of a Body, are as the *Squares* of the Times, from the beginning of the *Fall*.

Demonſtration. Let A B (*Fig.* 9. *Tab.* 4.) repreſent the *Time* of the *Fall* of a *Body*, B C perpendicular to A B, the *Velocity* acquired at the end of the *Fall*, and draw the Line A C; then divide the Line A B repreſenting the Time, into as many equal Parts as you pleaſe, as b, b, b, b, *&c.* and through theſe Points draw the Lines bc, bc, bc, bc, *&c.* parallel to B C, 'tis manifeſt that the ſeveral Lines, bc, repreſent the ſeveral *Velocities* of the falling Body, in ſuch Parts of the *Time* as A b is of A B, by the former Propoſition. It is evident likewiſe, that the *Area* A B C is the Sum of all the Lines bc being taken, according to the Method of *Indiviſibles*, infinitely many; ſo that the *Area* ABC repreſents the Sum of all the *Velocities*, between none and BC ſuppoſed infinitely many; which Sum is as the Space deſcended in the Time repreſented by AB. And by the ſame Reaſon the *Areas* A b c, will repreſent the Spaces deſcended in the Times A b; ſo then the Spaces deſcended in the Times A B, Ab, are as the *Areas* of the *Triangles* ABC, A b c, which by the 20th of the 6 of *Euclid*, are as the *Squares* of their *Homologous Sides* AB, Ab, that is to ſay, of the *Times*: Wherefore the Deſcents of *falling Bodies*, are as the *Squares* of the Times of their *Fall*, *Q. E. D.*

Prop. III. The *Velocity* which a *falling Body* acquires in any Space of time, is double to that, wherewith it would have moved the Space, deſcended by an equable Motion, in the ſame *time.*

Demonſtration. Draw the Line E C parallel to A B and A E parallel to B C in the ſame *Fig.* 9. and compleat the *Parallelogram* A B C E, it is evident that the *Area* thereof may repreſent the Space, a *Body* moved equably with the *Velocity* B C would deſcribe in the Time A B, and the *Triangle* ABC repreſents the *Space* deſcribed by the *Fall* of a *Body*, in the ſame Time AB, by the ſecond Propoſition. Now the *Triangle* A B C is half of the *Parallelogram* ABCE; and conſequently the Space deſcribed by the *Fall*, is half what would have been deſcribed by an *equable Motion* with the *Velocity* BC, in the ſame Time; wherefore the *Velocity* BC at the end of the *Fall*, is double to that *Velocity*, which in the Time AB, would have deſcribed the *Space fallen*, repreſented by the *Triangle* ABC, with an *equable Motion*, *Q. E. D.*

Prop. IV. All *Bodies* on or near the Surface of the *Earth*, in their *Fall*, deſcend ſo, as at the end of the firſt Second of Time, they have deſcribed 16 Feet, 1 Inch, *London Meaſure*, and acquired the *Velocity* of 32 Feet, 2 Inches, in a Second.

This is made out from the 25th Propoſition of the ſecond Part of that excellent Treatiſe of Mr. *Hugenius de Horologio Oſcillatorio*; wherein he demonſtrates the time of the leaſt *Vibrations* of a *Pendulum*, to be to the Time of the *Fall* of a *Body*, from the heighth of half the length of the *Pendulum*, as the *Circumference* of a *Circle* to its *Diameter*; whence, as a *Corollary*, it follows, that as the *Square* of the *Diameter* to the *Square* of the *Circumference*, ſo half the length of the *Pendulum* vibrating *Seconds*, to the *Space* deſcribed by the *Fall* of a *Body* in a *Second* of *Time*: And the Length of the *Pendulum* vibrating *Seconds*, being found 39, 125, or $\frac{1}{8}$ Inches, the *Deſcent* in a *Second* will be found by the aforeſaid *Analogy* 16 Foot and 1 Inch; and, by the third Propoſition, the *Velocity* will be double thereto; and near to this it hath been found by ſeveral Experiments, which by reaſon of the *ſwiftneſs* of the *Fall*, cannot ſo exactly determine its *Quantity*. The Demonſtration of *Hugenius* being the Concluſion of a long Train of *Conſequences*, I ſhall for brevity ſake omit; and refer you to his Book, where theſe things are more amply treated of.

From theſe Four *Propoſitions*, all *Queſtions* concerning the *Perpendicular Fall of Bodies*, are eaſily *ſolved*, and either *Time*, *Height*, or *Velocity* being aſſigned, one may readily find the other two. From them likewiſe is the Doctrine of *Projects* deducible, aſſuming the two following *Axioms*; *viz*. That a *Body* ſet a moving, will move on continually in a right *Line* with an *equable Motion*, unleſs ſome other Force or Impediment intervene, whereby it is accelerated, or retarded, or deflected.

Secondly, That a *Body* being agitated by two *Motions* at a time, does by their *compounded Forces* paſs through the ſame *Points*, as it would do, were the two *Motions divided* and acted *ſucceſſively*. As for Inſtance, Suppoſe a *Body* moved in the Line GF, (*Fig*. 1. *Tab*. 5.) from G to R, and there ſtopping, by another *Impulſe*, ſuppoſe it moved in a *Space* of *Time* equal to the former, from R towards K, to V. I ſay, the *Body* ſhall paſs through the Point V, tho' theſe two *ſeveral Forces* acted both in the *ſame time*.

Prop. V. The *Motion* of all *Projects* is in the *Curve* of a *Parabola*: Let the *Line* GRF (in *Fig*. 1.) be the *Line* in which the *Project* is directed, and in which by the firſt *Axiom* it would move equal *Spaces* in equal *Times*, were it not deflected downwards by the Force of *Gravity*. Let GB be the *Horizontal Line*, and GC a *Perpendicular* thereto. Then the *Line* GRF being divided into equal Parts, anſwering to equal *Spaces* of *Time*, let the *Deſcents* of the *Project* be laid down in *Lines parallel* to GC, proportioned as the *Squares* of the *Lines* GS, GR, GL, GF, or as the *Squares* of the *Times*, from S to T, from R to V, from L to X, and from F to B, and draw the *Lines* TH, VD, XY, BC parallel to GF; I ſay the Points T, V, X, B, are Points in the *Curve* deſcribed by the *Project*, and that that *Curve* is a *Parabola*. By the ſecond *Axiom*, they are Points in the *Curve*; and the Parts of the *Deſcent* GH, GD, GY, GC, = to ST, RV, LX, FB, being as the *Squares* of the *Times* (by the *ſecond Prop.*) that is, as the *Squares* of the *Ordinates*, HT, DU, YX, BC, equal to GS, GR, GL, GF, the *Spaces* meaſured in thoſe Times; and there being no other *Curve* but the *Parobola*, whoſe Parts of the *Diameter* are as the *Squares* of the *Ordinates*, it follows that the *Curve* deſcribed by a *Project*, can be no other than a *Parabola*: And ſaying, as RU the *Deſcent* in any *time*, to GR or UD the *direct Motion* in the ſame *time*, ſo is UD to a *third* proportional; that *third* will be the *Line* called by all Writers of *Conicks*, the *Parameter* of the *Parabola* to the *Diameter* GC, which is always the ſame in *Projects* caſt with the ſame *Velocity*: And the *Velocity* being defined by the Number of *Feet* moved in a *Second* of Time, the *Parameter* will be found by dividing the *Square* of the *Velocity*, by 16 *Feet*, 1 *Inch*, the *Fall* of a *Body* in the ſame *Time*.

Lemma.

The *Sine* of the double of any *Arch*, is equal to twice the *Sine* of that *Arch* into its *Co-ſine*, divided by *Radius*; and the *verſed Sine* of the *double* of any *Arch* is equal to twice the *Square* of the *Sine* thereof divided by *Radius*.

Let the *Arch* BC (in *Fig.*2. *Tab.*5.) be double the *Arch* BF, and A the *Center*; draw the *Radii* AB, AF, AC, and the *Chord* BDC, and let fall BE perpendicular to AC, and the *Angle* EBC, will be equal to the *Angle* ABD, and the *Triangle* BCE, will be like to the *Triangle* BDA; wherefore it will be as AB to AD, ſo BC or twice BD, to BE; that is, as *Radius* to *Co-ſine*, ſo twice *Sine*, to *Sine* of the double *Arch*. And as AB to BD, ſo twice BD or BC to EC, that is, as *Radius* to *Sine*, ſo twice that *Sine*, to the *Verſed Sine* of the double *Arch*; which two *Analogies* reſolved into *Equations*, are the *Propoſitions* contained in the *Lemma* to be proved.

Prop. VI. The *Horizontal* Diſtances of *Projections* made with the ſame *Velocity*, at ſeveral *Elevations* of the *Line* of Direction, are as the *Sines* of the doubled *Angles* of *Elevation*.

Let GB (*Fig.* 1.) the *Horizontal* Diſtance be $= z$, the *Sine* of the *Angle* of *Elevation*, FGB, be $= s$, its *Co-ſine* $= c$, *Radius* $= r$, and the *Parameter* $= p$. It will be as c to s; ſo z to $\frac{sz}{c}$=FB=GC, and by reaſon of the *Parabola* $\frac{psz}{c}$ = to the *Square* of CB, or GF,. Now as c to r, ſo is z to $\frac{zr}{c}$ = GF, and its *Square* $\frac{zzrr}{cc}$ will be therefore = to $\frac{psz}{c}$: which *Equation* reduced will be $\frac{psc}{rr} = z$. But by the former *Lemma* $\frac{2sc}{r}$ is equal to the *Sine* of the double *Angle*, whereof s is the *Sine*: Wherefore 'twill be as *Radius* to *Sine* of double the *Angle* FGB, ſo is half the *Parameter*, to the *Horizontal Range* or *Diſtance* ſought; and at the ſeveral *Elevations*, the *Ranges* are as the *Sines* of the double *Angles* of *Elevation* *Q.E.D.*

Corollary.

Hence it follows, that half the *Parameter* is the greateſt *Randon*, and that that happens at the *Elevation* of 45 Degrees, the *Sine* of whoſe double is *Radius*. Likewiſe that the *Ranges* equally diſtant above and below 45 are equal, as are the *Sines* of all doubled *Arches*, to the *Sines* of their doubled *Complements*.

Prop. VII. The *Altitudes* of *Projections* made with the ſame *Velocity*, at ſeveral *Elevations*, are as the *verſed Sines* of the doubled *Angles* of *Elevation*: As c is to s :: ſo is $\frac{p\,s\,c}{r\,r} =$ GB to $\frac{p\,s\,s}{r\,r} =$ BF: and UK $=$ RU $= \frac{\text{BF}}{4}$, the *Altitude* of the *Projection* $= \frac{p\,s\,c.}{4r\,r}$ Now by the foregoing *Lemma* $\frac{2\,s\,s}{r} =$ to the *verſed Sine* of the double *Angle*, and therefore it will be as *Radius*, to *verſed Sine* of double the *Angle* FGB, ſo an 8th of the *Parameter* to the height of the *Projection* VK; and ſo theſe heights at ſeveral *Elevations*, are as the ſaid *verſed Sines*, *Q. E. D.*

Corollary.

From hence it is plain, that the greateſt *Altitude* of the perpendicular *Projection* is a 4th of *Parameter*, or half the greateſt *Horizontal Range*; the *verſed Sine* of 180 Degrees being $= 2r$.

Prop. VIII. The *Lines* G F, or Times of the Flight of a *Project* caſt with the ſame Degree of *Velocity* at different *Elevations*, are as the *Sines* of the *Elevations*.

As c is to r :: ſo is $\frac{psc}{rr} =$ GB by the 6 Prop. to $\frac{ps}{r} =$ GF, that is, as *Radius* to *Sine* of *Elevation*, ſo the *Parameter* to the *Line* GF; ſo the *Lines* GF are as the *Sines* of *Elevation*, and the *Times* are proportional to thoſe *Lines*; wherefore the *Times* are as the *Sines* of *Elevation*: *Ergo conſtat propoſitio.*

Prop. IX. Problem. A *Projection* being made as you pleaſe, having the Diſtance and Altitude, or Deſcent, of an Object, through which the Project paſſes, together with the *Angle* of *Elevation* of the *Line* of *Direction*; to find the *Parameter* and *Velocity*, that is (in *Fig.* 1.) having the *Angle* FGB, GM, and MX.

Solution. As *Radius* to *Secant* of FGB, ſo GM the *Diſtance* given to GL; and as *Radius* to *Tangent* of FGB, ſo GM to LM. Then LM − MX in *Heights*, or + MX in *Deſcents*; or elſe MX − ML, if the *Direction* be below the *Horizontal Line*, is the *Fall* in the *Time* that the direct *Impulſe* given in G would have carried the Project from G to L=LX=GY; then by

Reaſon of the *Parabola*, as LX or GY, is to GL or YX, :: ſo is GL to the *Parameter* ſought. To find the *Velocity* of the *Impulſe*: by Prop. 2, and 4, find the Time in Seconds that a Body would fall the Space LX; and by that dividing the Line GL, the *Quote* will be the *Velocity*, or Space moved in a Second ſought, which is always a mean Proportional between the *Parameter*, and 16 Feet, 1 Inch.

Prop. X. Problem 2. Having the *Parameter*, Horizontal Diſtance, and Height or Deſcent of an *Object*, to find the Elevations of the Line of Direction neceſſary to hit the given *Object*; that is, having GM, MX, and the greateſt *Randon* equal to half the *Parameter*; to find the *Angles* FGB.

Let the *Tangent* of the *Angle* ſought be $=t$, the *Horizontal Diſtance* GM$=b$, the Altitude of the *Object* MX$=h$, the *Parameter* $=p$, and *Radius*$=r$, and it will be,

As r to [illegible] ſo b to $\frac{tb}{r}=$ML and $\frac{tb}{r}\mp h$ in aſcents $=$LX, and in deſcents

$\frac{ptb}{r}\mp ph=$GL *quad.* $=$XY *quad. ratione Parabolæ*; but

$bb\mp\frac{tt\,bb}{rr}=$GL *quad.* 47. 1. *Euclid.* Wherefore

$\frac{ptb}{r}\mp ph=bb\mp\frac{ttbb}{rr}$ which Equation tranſpoſed, is

$\frac{ttbb}{rr}=\frac{ptb}{r}\mp ph-bb$, divided by bb is

$\frac{tt}{rr} = \frac{pt}{br} \mp \frac{ph}{bb} - 1$. this Equation ſhews the Queſtion to have 2 Anſwers, and the Roots thereof are $\frac{t}{r} = \frac{p}{2b} + \sqrt{\frac{pp \pm 4ph}{4bb} - 1}$ from which I derive the following Rule.

Divide half the *Parameter* by the Horizontal diſtance, and keep the Quote; *viz.* $\frac{p}{2b}$ then ſay, as *ſquare* of the *diſtance* given to the half *Parameter*, ſo half *Parameter* $\mp$ double height deſcent to the *ſquare* of a *Secant* $= \frac{pp \mp 4ph}{4bb}$. The *Tangent* anſwering to that *Secant*, will be $\sqrt{\frac{pp \mp 4ph}{4bb} - 1}$ or Square of Radius, ſo then the ſum and difference of the aforefound *Quote*, and this *Tangent* will be the Roots of the *Equation*, and the *Tangents* of the *Elevations* ſought.

Note here, that in *Deſcents*, if the *Tangent* exceed the *Quote*, as it does when ph is more than bb, the *direction* of the lower *Elevation* will be below the *Horizon*, and if $ph = bb$, it muſt be directed *Horizontal*, and the *Tangent* of the upper *Elevation* will be $\frac{pr}{b}$: Note likewiſe, that if $4bb + 4ph$ in *aſcents*, or $4bb - 4ph$ in *deſcents*, be equal to pp, there is but one *Elevation* that can hit the *Object*, and its *Tangent* is $\frac{pr}{2b}$. And if $4bb + 4ph$ in *aſcents*, or $4bb - 4ph$ in *deſcents*, do exceed pp, the *Object* is without the reach of a *Project* caſt with that *Velocity*, and ſo the thing impoſſible.

From this *Equation* $4bb \mp 4ph = pp$ are determined the utmoſt limits of the reach of any *Project*, and the Figure aſſigned, wherein are all the *heights* upon each *Horizontal diſtance* beyond which it cannot paſs; for by reduction of that *Equation*, h will be found $= \frac{1}{4}p - \frac{bb}{p}$ in *heights*, and $\frac{bb}{p} - \frac{1}{4}p$ in *deſcents*; from whence it follows, that all the Points h are in the *Curve* of the *Parabola*, whoſe *Focus* is the Point from whence the *Project* is caſt, and whoſe *Latus rectum*, or *Parameter ad Axem* is $= p$. Likewiſe from the ſame *Equation* may the leaſt *Parameter* or *Velocity* be found capable to reach the *Object* propoſed; for $bb = \frac{1}{4}pp \mp ph$ being reduced $\frac{1}{2}p$ will be $= \sqrt{bb+hh} \pm h \begin{matrix}\text{in aſcents}\\ \text{in deſcents,}\end{matrix}$ which is the *Horizontal Range* at 45 degrees, of a Project caſt with the leaſt Velocity that would juſt reach the *Object*, and the *Elevation* requiſite will be eaſily had; for dividing the ſo found *Semi-parameter* by the *Horizontal diſtance* given b, the *Quote* into *Radius* will be the *Tangent* of the *Elevation* ſought. This Rule may be of good uſe to all *Bombardiers* and *Gunners*, not only that they may uſe no more Pouder than is neceſſary, to caſt their *Bombs* into the place aſſigned, but that they may ſhoot with much more certainty, for that a ſmall Error committed in the *Elevation* of the *Piece*, will produce no ſenſible Difference in the fall of the

Shot : For which Reaſons the *French* Engineers in their late Sieges have uſed Mortar-pieces inclin'd conſtantly to the *Elevation* of 45, proportioning their Charge of Pouder according to the diſtance of the *Object* they intend to ſtrike on the *Horizon.*

And this is all that need to be ſaid concerning this *Problem* of ſhooting upon *Heights* and *Deſcents.* But if a *Geometrical* Conſtruction thereof be required ; I think I have one that is as eaſy as can be expected, which I deduce from the foregoing *Analytical Solution,* *viz.* $\frac{t}{r} = \frac{p}{2b} \pm \frac{\sqrt{\frac{1}{4}pp \pm pb - bb},}{bb}$ and'tis this having made the right Angle GDF,(*Tab.* 5. *Fig.* 3.) make D F $= \frac{1}{2}p$, or greateſt Range, and G D $= b$ the Horizontal Diſtance, and D B $= h$ the perpendicular heighth of the Object; to be laid upwards from D, if the Object be above the Horizon, or downwards if below it. Parallel to G D draw F A, and make it equal to G B the Hypothenuſal Diſtance of the Object; and with the Center A and Radius F B $= \frac{1}{2}p \pm h$ ſweep an Arch, which ſhall if the thing be poſſible, interſect the indeterminate Perpendicular D F in two Points K and L, to which draw the Lines, G L, G K, I ſay, the Angles D G K, D G L, are the Elevations requiſite to ſtrike the Object B.

Demonſtration. The Sq. of F K or F L, is equal to F B q — G B q: or $\overline{\frac{1}{2}p \pm h}^2 - bb - hh$ or $\frac{1}{4}pp \pm ph - bb$, and therefore $\sqrt{\frac{1}{4}pp \pm ph - bb}$ is $=$ F K $=$ F L, and by Conſequence D K, D L $= \frac{1}{2}p \pm \sqrt{\frac{1}{2}pp \pm ph - bb}$. And as D G : D K and D L :: Radius : Tangents ſought, which coincides with our Algebraical Expreſſion thereof.

*Prop.*XI.To determine the Force or *Velocity* of a *Project*,in every Point of the *Curve* it deſcribes.

To do this we need no other *Præcognita*, but only the third Propoſition, *viz.* That the *Velocity* of *falling Bodies*, is double to that which in the ſame time, would have deſcribed the Space *fallen* by an equable Motion : For the *Velocity* of a Project, is compounded of the conſtant equal *Velocity* of the impreſſed Motion, and the *Velocity* of the *Fall*, under a given *Angle*, *viz.* the Complement of the *Elevation:* For Inſtance, in *Fig.* 2. in the time wherein a Project would moue from G to L, it deſcends from L to X, and by the third *Propoſition* has acquired a *Velocity*, which in that time would have carried it by an equable Motion from L to Z, or twice the Deſcent L X; and drawing the Line G Z, I ſay, the *Velocity* in the Point X, compounded of the *Velocities* G L and L Z under the Angle G L Z, is to the *Velocity* impreſt in the Point G, as G Z is to G L; this follows from our ſecond *Axiome*, and by the 20 and 21 *Prop. lib.* 1. *conic. Midorgii*, X O parallel and equal to G Z ſhall touch the *Parabola* in the Point X. So that the *Velocities* in the ſeveral Points, are as the lengths of the *Tangents* to the *Parabola* in thoſe Points, intercepted between any two *Diameters :* And theſe again are as the *Secants* of the *Angles*, which thoſe *Tangents* continued make with the *Horizontal* Line G B. From what is here laid down,may the comparative Force of a *Shot* in any two Points of the *Curve*, be either *Geometrically* or *Arithmetically* diſcovered.

Corollary,

Corollary.

From hence it follows, that the force of a Shot is always leaſt at U, or the *Vertex* of the *Parabola*, and that at equal diſtances therefrom, as at T and X, G and B its force is always equal, and that the leaſt force in U is to that in G and B, as *Radius* to the Secant of the *Angle* of *Elevation* F G B.

Theſe *Propoſitions* conſidered, there is no queſtion relating to *Projects*, which, by the help of them, may not eaſily be Solved; and tho' it be true that moſt of them are to be met withal, in *Galileus Torricellius* and others, who have taken them from thoſe Authors, yet their Books being Forreign, and not eaſy to come by, and their *Demonſtrations* long and difficult, I thought it not amiſs to give the whole *Doctrine* here in *Engliſh*, with ſuch ſhort *Analytical* Proof of my own, as might be ſufficient to evince their Truth.

The Tenth *Propoſition* contains a *Problem*, untouch'd by *Torricellius*, which is of the greateſt uſe in *Gunnery*, and for the ſake of which this *Diſcourſe* was principally intended: It was firſt Solved by Mr. *Anderſon*, in his Book of the Genuine Uſe and Effects of the *Gun*, Printed in the Year 1674; but his Solution required ſo much Calculation, that it put me upon ſearch, whether it might not be done more eaſily, and thereupon in the Year 1678 I found out the Rule I now Publiſh, and from it the *Geometrical* Conſtruction: Since which time there has a large *Treatiſe* of this Subject Intitl'd, *L'art de jetter les Bombes*, been Publiſh'd by *Monſieur Blondel*, wherein he gives the Solutions of this *Problem* by *Meſſieurs Buot*, *Romer* and *de la Hire*: But none of them being the ſame with mine, or, in my Opinion, more eaſy, and moſt of them more Operoſe, and beſides mine finding the *Tangent*, which generally determines the *Angle* better than its *Sine*, I thought my ſelf obliged to Print it for the uſe of all ſuch, as deſire to be informed in the *Mathematical* part of the Art of *Gunnery*.

Now theſe Rules were rigidly true, were it not, as I ſaid before, for the Oppoſition of the Medium, whereby not only the direct impreſt Motion is continually retarded, by likewiſe the increaſe of the *Velocity* of the *Fall*, ſo that the ſpaces deſcribed thereby, are not exactly as the ſquares of the Times: But what this Oppoſition of the *Air* is, againſt ſeveral *Velocities*, *Bulks*, and *Weights*, is not ſo eaſy to determine. 'Tis certain that the weight of *Air* to that of *Water*, is nearly as 1 to 800, whence the weight thereof, to that of any *Project* is given; 'tis very likely, that to the ſame *Velocity*, and *Magnitude*, but of different matter, the *Oppoſition* ſhould be *reciprocally* as the weights of the Shot; as likewiſe that to Shot of the ſame *Velocity* and Matter, but of different Sizes, it ſhould be as the *Diameters reciprocally*: Whence generally the *Oppoſition* to Shot with the ſame *Velocity*, but of differing *Diameters*, and *Materials*, ſhould be as their *Specifick Gravities* into their *Diameters reciprocally*; but whether the *Oppoſition*, to differing *Velocities* of the ſame Shot, be as the *Squares* of thoſe *Velocities*,

ties, or as the *Velocities* themſelves, or otherwiſe, is yet a harder Queſtion. However it be, 'tis certain, that in large Shot of *Mettal*, whoſe weight many Thouſand times ſurpaſſes that of the *Air*, and whoſe force is very great, in proportion to the *Surface* wherewith they preſs thereon; this *Oppoſition* is ſcarce diſcernable: For by ſeveral *Experiments* made with all Care and Circumſpection with a *Morterpeice*, Extraordinary well fixt to the Earth on purpoſe, which carried a ſolid Braſs Shot of four Inches and a half *Diameter*, and of about fourteen Pound Weight, the *Ranges* above and below forty five *Degrees* were found nearly equal; if there were any difference, the under *Ranges* went rather the fartheſt, but thoſe differences were uſually leſs than the Errours committed in ordinary Practice, by the unequal Goodneſs and Dryneſs of the ſame ſort of Pouder, by the Unfittneſs of the Shot to the Bore, and by the Looſneſs of the Carriage.

In a ſmaller Braſs-Shot of about an Inch and half Diameter, caſt by a Croſs-Bow which ranged it, at moſt about four Hundred Foot, the Force being much more equal than in the Morterpiece, this difference was found more Curiouſly: and Conſtantly and moſt Evidently, the under Ranges out went the upper. From which Trials I conclude, that altho' in ſmall and light Shot, the Oppoſition of the Air, ought and muſt be accounted for; yet in Shooting of great and weighty Bombs, there need be very little or no allowance made; and ſo theſe Rules may be put in practice to all

Intents and Purpoſes, as if this Impediment were abſolutely remov'd.

A Propoſition of general Uſe in the Art of Gunnery, ſhewing the Rule of laying a Mortar to paſs, in order to ſtrike an Object above or below the Horizon.

It was formerly the Opinion of thoſe concerned in Artillery, that there was a certain requiſite of Pouder for each Gun, and that in Mortars, where the diſtance was to be varied, it muſt be done by giving a greater or leſſer Elevation to the Peice. But now our later Experience has taught us that the ſame thing may be more certainly and readily performed by increaſing and diminiſhing the quantity of Pouder, whether regard be had to the Execution to be done, or to the Charge of doing it. For when Bombs are diſcharged with great Elevations of the Mortar, they fall too Perpendicular, and bury themſelves too deep in the Ground, to do all that damage they might, if they came more Oblique, and broke upon or near the Surface of the Earth; which is a thing acknowledged by the Beſieged in all Towns, who unpave their Streets, to let the Bombs bury themſelves, and thereby ſtifle the force of their Splinters. A Second Convenience is, that at the extream Elevation, the Gunner is not obliged to be ſo curious in the direction of his Piece, but it will ſuffice to be within a Degree or two of the Truth; whereas in the other method of Shooting he ought to be very curious. But a Third, and no leſs conſiderable Advantage is, in the ſaving the

Prince's Pouder, which in ſo great and ſo numerous Diſcharges, as we have lately ſeen, muſt needs amount to a conſiderable Value. And for Sea-Mortars, it is ſcarce practicable otherwiſe to uſe them, where the agitation of the Sea continually changes the Direction of the Mortar, and would render the Shot very uncertain, were it not that they are placed about 45 Degrees Elevation, where ſeveral Degrees above or under, makes very little difference in the Effect.

In the precedent Dſcourſe, I conſidered all the Propoſitions relating to the Motion of Projectiles, and gave a Solution to this Problem; *viz. To hit an Object above or below the Horizontal Line with the greateſt Certainty and leaſt Force.* That is, that the Horizontal diſtance of the Object being put $=b$, and the Perpendicular Heighth $=h$, the Charge requiſite to ſtrike the Object with the greateſt Advantage, was that which with an Elevation of 45° would caſt the Shot on the Horizontal Line, to the diſtance of $\sqrt{+bb\,bh}+h$ when the Object was above the Horizon; or if it were below it, the Charge muſt be leſſer, ſo as to reach on the Horizon, at 45° Elevation, no greater a Diſtance than $\sqrt{bb+hh}-h$; that is, in the one Caſe, the Sum of the Hypothenuſal Diſtance of the Object from the Gun, and the Perpendicular Heighth thereof above the Gun; and in the other Caſe, when the Object is below the Horizon, the difference of the ſame *per* 47. 1 *Eucl.* And I then ſhew'd how to find the Elevation proper for the Gun ſo charged, *viz.* As the

Horizontal Diſtance of the Object, to the Sum or Difference of the Hypothenuſal Diſtance and Perpendicular Heighth :: So Radius to the Tangent of the Elevation ſought. But I was not at that time aware that the aforeſaid Elevation did conſtantly biſect the Angle between the Perpendicular and the Object, as is demonſtrated from the Difference and Sum of the *Tangent* and *Secant* of any Arch being always equal to the *Tangent* and and *Cotangent* of the half Complement thereof to a Quadrant. Having diſcovered this, I think nothing can be more compendious, or bids fairer to compleat the Art of Gunnery, it being as eaſie to ſhoot with a Mortar at any Object on demand, as if it were on the Level; neither is there need of any Computation, but only ſimply laying the Gun to paſs, in the middle Line between the Zenith and the Object, and giving it its due Charge. Nor is there any great need of Inſtruments for this purpoſe: For if the Muzzle of the Mortar be turned truly Square to the Bore of the Piece, as it uſually is or ought to be, a Piece of Looking-glaſs Plate applied parallel to the Muzzle, will by its Reflection give the true Poſition of the Piece, the Bombardeer having no more to do, but to look perpendicularly down on the Looking-glaſs, along a ſmall Thread with a Plumbet, and to raiſe or depreſs the Elevation of the Piece, till the Object appear reflected on the ſame Point of the *Speculum*, on which the Plumbet falls; for the Angle of Incidence and Reflection being equal, in this Caſe a Line at Right Angles to the *Speculum*, as is the *Axis* of the Chaſe of the Piece, will biſect the Angle between the Perpendicular and the Object, according as our Propoſition requires. So that it only remains by good and valid Experiments to be aſſured of the Force of Gunpouder, how to make and conſerve it equal, and to know the Effect thereof in each Piece; that is, how far differing Charges will caſt the ſame Shot out of it; which may moſt conveniently be engraven on the outſide thereof, as a ſtanding Direction to all Gunners, who ſhall from thence forward have occaſion to uſe that Piece: And were this Matter well aſcertained, it might be worth the while to make all Mortars of the like Diameter as near as may be, alike in length of Chaſe, Weight, Chamber, and all other Circumſtances.

This Diſcovery that the utmoſt Range on an inclined Plane, is, when the *Axis* of the Piece makes equal Angles with the Perpendicular and the Object, compared with what I have demonſtrated of the ſame Problem in the aforeſaid Diſcourſe does lead to and diſcover two very ready Theorems; the one, to find the greateſt Horizontal Range at 45° Elevation, by any Shot made upon any inclined Plane, with any Elevation of the Piece whatſoever: And the other to find the Elevations proper to ſtrike a given Object, with any Force greater than what ſuffices to reach it with the aforeſaid middle Elevation. Both which being performed by one ſingle Proportion, may be very ſerviceable to ſuch as are concerned in the Practice of Gunnery, but are unwilling to trouble themſelves with tedious and difficult Rules. The two Propoſitions are theſe.

PROP. I.

A Shot being made on an inclined Plane, having the Horizontal Diſtance of the Object it ſtrikes, with the Elevation of the Piece, and the Angle at the Gun between the Object and the Perpendicular; to find the greateſt Horizontal Range of that Piece, laden with the ſame Charge; that is, half the *Latus rectum* of all the *Parabola* made with the ſame *Impetus.*

RULE.

Take half the Diſtance of the Object from the *Nadir*, and take the Difference of the given Elevation from that half; the Verſed Sine of that Difference ſubtract from the Verſed Sine of the Diſtance of the Object from the *Zenith:* Then ſhall the Difference of thoſe Verſed Sines be to the Sine of the Diſtance of the Object from the *Zenith*, as the Horizontal Diſtance of the Object ſtrook, to the greateſt Horizontal Range at 45°.

PROP. II.

Having the greateſt Horizontal Range of a Gun, the Horizontal Diſtance and Angle of Inclination of an Object to the Perpendicular, to find the two Elevations neceſſary to ſtrike that Object.

RULE.

RULE.

Halve the Diſtance of the Object from the *Nadir*; this half is always equal to the half Sum of the two Elevations we ſeek. Then ſay, *As the greateſt Horizontal Range is to the Horizontal Diſtance of the Object: So is the Sine of the Angle of Inclination or Diſtance of the Object from the Perpendicular, to a fourth Proportional; which fourth being ſubtracted from the Verſed Sine of the Diſtance of the Object from the* Zenith, *leaves the Verſed Sine of half the Difference of the Elevations ſought; which Elevations are therefore had by adding and ſubtracting that half Difference to and from the aforeſaid half Sum.*

I ſhall not need to ſpeak of the Facility of theſe Solutions, I ſhall only obſerve that they are both General, without Exception or Caution, and derived from the Knowledge that theſe two Elevations are equidiſtant above and below the Line, biſecting the Angle between the Object and the *Zenith*,

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A Diſcourſe concerning the Meaſure of the Airs reſiſtance to Bodies moved in it. By the Learned John Wallis, *S. T. D. and R. S. Soc.*

1. THAT the Air (and the like of any other *Medium*) doth conſiderably give reſiſtance to Bodies moved in it; (and doth thereby abate their Celerity and Force:) is generally admitted. And Experience doth atteſt it: For otherwiſe, a Cannot-Bullet projected Horizontally, ſhould (ſuppoſing the Celerity and Force undiminiſhed) ſtrike as hard againſt a perpendicular Wall, erected at a great diſtance, as near at hand; which we find it doth not.

2. But at what Rate, or in what Proportion, ſuch reſiſtance is; and (conſequently, at what Rate the Celerity and Force is continually diminiſhed) ſeems not to have been ſo well examined. Whence it is, that the Motion of a Project (ſecluding this Conſideration) is commonly reputed to deſcribe a Parabolick Line; as ariſing from an uniform or equal Celerity in the Line of Projection, and a Celerity uniformly accelerated in the Line of Deſcent; which two ſo compounded, do create a Parabola.

3. In order to the Computation hereof, I firſt premiſe this *Lemma*, (as the moſt rational that doth occur for my firſt footing,) That (ſuppoſing other things equal) the reſiſtance is proportional to the Celerity. For in a double Celerity, there is to be removed (in the ſame time) twice as much Air, (which is a double Impediment) in a treble, thrice as much; and ſo in other Proportions.

4. Suppoſe we then the Force impreſſed (and conſequently the Celerity, if there were no reſiſtance) as 1; the reſiſtance as r. (which muſt be leſs than the Force, or elſe the Force would not prevail over the Impediment, to create a Motion.) And therefore the effective Force at a firſt Moment, is to be reputed as $1-r$: That is, ſo much as the Force impreſſed, is more than the Impediment or Reſiſtance.

5. Be it as $1-r$ to 1; ſo one to m. (which m is therefore greater than 1.)

6. And therefore the effective Force (and conſequently the Celerity) as to a firſt Moment, is to be $\frac{1}{m}$ of what it would be, had there been no reſiſtance.

7. This $\frac{1}{m}$ is alſo the remaining Force after ſuch firſt Moment; and this remaining Force is (for the ſame Reaſon) to be proportionally abated as to a ſecond Moment; that is, we are to take $\frac{1}{m}$ thereof, that is $\frac{1}{mm}$ of the impreſſed Force. And for a third Moment (at equal diſtance of time) $\frac{1}{mmm}$; for a fourth $\frac{1}{m^4}$; and ſo onward infinitely.

8. Becauſe the length diſpatched (in equal times) is proportional to the Celerities; the Lines of Motion (anſwering to thoſe equal Times) are to be as $\frac{1}{m}$, $\frac{1}{m^2}$, $\frac{1}{m^3}$, $\frac{1}{m^4}$, *&c.* of what they would have been, in the ſame Times, had there been no reſiſtance.

9. This therefore is a Geometrical Progreſſion; and (becauſe of *m* greater than 1) continually decreaſing.

10. This decreaſing Progreſſion infinitely continued (determining in the ſame Point of Reſt, where the Motion is ſuppoſed to expire) is yet of a finite Magnitude; and equal to $\frac{1}{m-1}$ of what it would have been in ſo much Time, if there had been no reſiſtance. As is demonſtrated in my Algebra, *Chap.* 95. *Prop.* 8. For (as I have elſewhere demonſtrated) the Sum or Aggregate of a Geometrical Progreſſion is $\frac{VR-A}{R-1}$ (ſuppoſing V the greateſt Term, A the leaſt, and R the common Multiplier.) That is $\frac{VR}{R-1} - \frac{A}{R-1}$. Now in the preſent Caſe, (ſuppoſing the Progreſſion infinitely continued) the leaſt Term A, becomes infinitely ſmall, or $= 0$. And conſequently $\frac{A}{R-1}$ doth alſo vaniſh, and thereby the Aggregate becomes $= \frac{VR}{R-1}$. That is

(as will appear by dividing VR by $R-1$;) $V+\frac{V}{R}+\frac{V}{RR}+\frac{V}{R^3}+$ &c. $=\frac{VR}{R-1}$; (ſuppoſing the Progreſſion to begin at $V=1$.) That is (dividing all by R, that ſo the Progreſſion may begin at $\frac{V}{R}=\frac{1}{m}$:) $\frac{V}{R-1}=\frac{V}{R}+\frac{V}{RR}+\frac{V}{R^3}$, + &c. That is, in our preſent Caſe (becauſe of $V=1$, & $R=m$:) $\frac{1}{m}+\frac{1}{mm}+\frac{1}{m^3}$ &c. $=\frac{1}{m-1}$. That is, (putting $n=m-1$) $\frac{1}{n}$ of what it would have been if there had been no reſiſtance.

$$\begin{array}{l} R-1)VR(V+\frac{V}{R},\ \frac{V}{RR}\ \&c. \\ \underline{VR-V} \\ +V \\ \underline{+V-\frac{V}{R}} \\ +\frac{V}{R} \\ \underline{+\frac{V}{R}-\frac{V}{RR}} \\ +\frac{V}{RR} \\ \&c. \end{array}$$

11. This infinite Progreſſion is fitly expreſſed by an Ordinate in the exterior Hyperbola, parallel to one of the Aſymptotes; and the ſeveral Members of that, by the ſeveral Members of this, cut in continual Proportion, As is there demonſtrated at *Prop.* 15. For let *S H*, (*vid.*Fig. 4. Tab.5.) be an Hyperbola between the Aſymptotes *A B*, *A F*: And let the Ordinate *D H* (in the exteriour Hyperbola, parallel to *A F*,) repreſent the impreſſed Force undiminiſhed; or the Line to be deſcribed in ſuch time, by a Celerity anſwerable to ſuch undiminiſhed Force. And let *B S* (a like Ordinate) be $\frac{1}{m}$ thereof; which therefore, being leſs than *D H* (as being equal to a Part of it) will be farther than it from *A F*. In *A B* (which I put = 1) let *B d* be ſuch a Part thereof, as is *B S* of *D H*.

Now becauſe (as is well known) all the inſcribed Parellelograms, in the exterior Hyperbola, *A S*, *A H*, *&c.* are equal; and therefore their ſides reciprocal: Therefore as *A d* $= 1 - \frac{1}{m}$ (ſuppoſing *B d* to be taken, from *B* toward *A*,) to *A B* $= 1$, (or as $m - 1$ to m:) ſo is *B S* $= \frac{1}{m}$ *D H*, to *d h*, which is therefore equal to $\frac{1}{m-1}$ of *D H*; that is (as will appear by dividing 1, by $m - 1$,) to $\frac{1}{m} + \frac{1}{mm} + \frac{1}{m^3}$ *&c.* of *D H*.

$$\begin{array}{l} m-1)\ 1\ \left(\frac{1}{m}+\frac{1}{mm}+\frac{1}{m^3}+\&c.\right. \\ \quad 1-\frac{1}{m} \\ \hline \quad +\frac{1}{m} \\ \quad +\frac{1}{m}-\frac{1}{mm} \\ \hline \qquad +\frac{1}{mm} \\ \qquad +\frac{1}{mm}-\frac{1}{mmm} \\ \hline \qquad\qquad +\frac{1}{mmm} \\ \quad \&c. \end{array}$$

Or if *B d* be taken beyond *B*; then as *A d* $= 1 + \frac{1}{m}$, to *AB* $= 1$, or as $m + 1$ to m, ſo is $\frac{1}{m}$ *D H* to *d h*, which is therefore equal to $\frac{1}{m+1}$ *D H*; that is (as will appear by like dividing of 1 by $m + 1$;) $=$ to $\frac{1}{m} - \frac{1}{mm} + \frac{1}{m^3} -$ *&c.* of *D H*.

12. Let ſuch ordinate *d h*, or (equal to it in the Aſymptote) *A F*, be ſo divided in *L*, *M*, *N*, *&c.* (by Perpendiculars cutting the Hyperbola in *l*, *m*, *n*, *&c.*) as that *F L*, *L M*

MN be as $\frac{1}{m}$, $\frac{1}{mm}$, $\frac{1}{m^3}$ *&c.* That is, ſo continually decreaſing, as that each Antecedent be to its Conſequent, as 1 to $\frac{1}{m}$, or as *m* to 1. See *Fig.* 5. *Tab.* 5.

13. This is done by taking *AF*, *AL*, *AN*, *&c.* in ſuch proportion. For, of continual Proportionals, the differences are alſo continually proportional, and in the ſame proportion. For let *A*,*B*,*C*,*D*, *&c.* be ſuch Proportionals, and their Differences *a*, *b*, *c*, *&c.* That is $A-B=a$, $B-C=b$, $C-D$, $=c$, *&c.*

Then, becauſe A, B, C, D, *&c.* are in continual proport.
That is A. B :: B. C :: C. D :: *&c.*
And dividing A − B. B :: B − C. C :: C − D. D :: *&c.*
That is *a*. B :: *b*. C :: *d*. D :: *&c.*
And alternly *a*. *b*. *c*. *&c.* :: B. C. D. *&c.* :: A. B. C. *&c.*
That is, in continual proportion as A to B, or as *m* to 1.

14. This being done; the Hyperbolick Spaces *Fl*, *Lm*, *Mn*, &c. are equal. As is demonſtrated by *Gregory San-Vincent*; and as ſuch is commonly admitted.

15. So that *Fl*, *Lm*, *Mn*, *&c.* may fitly repreſent equal Times, in which are diſpatched unequal Lengths, repreſented by *FL*, *LM*, *MN*, *&c.*

16. And becauſe they are in Number infinite (though equal to a finite Magnitude) the Duration is infinite: And conſequently the impreſſed Force, and Motion thence ariſing,

ſing, never to be wholly extinguiſhed (without ſome further Impediment) but perpetually approaching to *A*, in the Nature of Aſymptotes.

17. The Spaces *Fl*, *Fm*, *Fn*, *&c.* are therefore as Logarithms (in Arithmetical Progreſſion increaſing) anſwering to the Lines *AF*, *AL*, *AM*, *&c.* or to *FL*, *LM*, *MN*, *&c.* in Geometrical Progreſſion decreaſing.

18. Becauſe *FL*, *LM*, *MN*, *&c.* are as $\frac{1}{m}$, $\frac{1}{mm}$, $\frac{1}{m^3}$, *&c.* (infinitely) terminated at *A*; therefore (by ¶ 10) their Aggregate *FA* or *dh*, is to *DH*, (ſo much Length as would have been diſpatched, in the ſame time, by ſuch impreſſed Force undiminiſhed) as 1 to $m - 1 = n$.

19. If therefore we take, as 1 to *n*, ſo *AF* to *DH*; this will repreſent the Length to be diſpatched, in the ſame time, by ſuch undiminiſhed Force.

20. And if ſuch *DH* be ſuppoſed to be divided into equal Parts innumerable (and therefore infinitely ſmall;) theſe anſwer to thoſe (as many) Parts unequal in *FA*, or *hd*.

21. But, what is the Proportion of *r* to 1, or (which depends on it) of $1 - r$ to 1, or 1 to *m*; remains to be inquired by Experiment.

22. If the Progreſſion be not infinitely continued; but end (ſuppoſe) at *N*, and its leaſt Term be $A = MN$; then, out of $\frac{V}{R-1} = \frac{1}{m} + \frac{1}{m.m} + \frac{1}{m^3}$, *&c.* is to be ſubducted $\frac{A}{R-1}$ (as at ¶ 10) that is (as by Diviſion

ſion will appear) $\frac{A}{R} + \frac{A}{R^2} + \frac{A}{R^3}$ &c. That is (in our preſent Caſe) $\frac{a}{m} + \frac{a}{mm} + \frac{a}{m^3}$ &c. And ſo the Aggregate will be $\frac{1-a}{m} + \frac{1-a}{mm} + \frac{1-a}{m^3}$ &c. $= \frac{1-a}{n}$.

And thus as to the Line of Projection, in which (ſecluding the Reſiſtance,) the Motion is reputed uniform; diſpatching equal Lengths in equal Times. Conſider we next the Line of Deſcent.

23. In the Deſcent of Heavy Bodies, it is ſuppoſed that to each Moment of Time, there is ſuperadded a new Impulſe of Gravity to what was before: And each of theſe, ſecluding the Conſideration of the Air's Reſiſtance, to proceed equally (from their ſeveral beginnings) through the ſucceeding Moments. As (in the erect Lines) 1 1 1 1 &c. 1 1 1 &c. 1 1 &c. 1 &c. and ſo continually as in the Line of Projection.

1
1 1
1 1 1
1 1 1 1
&c.

24. Hence ariſeth (in the tranſverſe Lines) for the firſt Moment 1, for the ſecond 1 + 1, for the third 1 + 1 + 1, and ſo forth, in Arithmetical Progreſſion: As are the Ordinates in a Triangle, at equal diſtance.

25. And ſuch are the continual Increments of the Diameter, or of the Ordinates in the exterior Parabola, anſwering to the interior Ordinates, or Segments of the Tangent, equally increaſing; as is known, and commonly admitted.

26. If we take in the Conſideration of the Air's Reſiſtence; we are then for each of theſe equal Progreſſions, to ſubſtitute a decreaſing Progreſſion Geometrical; in like manner (and for the ſame Reaſons) as in the Line of Projection.

27. Hence ariſeth, for the firſt Moment $\frac{1}{m}$; for the ſecond $\frac{1}{m} + \frac{1}{m^2}$; for the third $\frac{1}{m} + \frac{1}{m^2} + \frac{1}{m^3}$ *&c.* And ſuch is therefore the Deſcent of a heavy Body falling by its own weight. The ſeveral Impulſes of Gravity being ſuppoſed equal.

$$\begin{array}{llll} \frac{1}{m} & & & \\ \frac{1}{m^2}, & \frac{1}{m} & & \\ \frac{1}{m^3}, & \frac{1}{m^2}, & \frac{1}{m} & \\ \frac{1}{m^4}, & \frac{1}{m^3}, & \frac{1}{m^2}, & \frac{1}{m} \end{array}$$

28. That is (in the Figure of ¶ 12) as *F L*, *F M*, *F N*, *&c.* in the Line of Deſcent, anſwering to *F L*, *L M*, *M N*, *&c.* in the Line of Projection.

29. But though the Progreſſions for the Line of Projection, are like to each of thoſe many in the Line of Deſcent; it is not to be thence inferred, that therefore $\frac{1}{m}$ in the one, is equal to $\frac{1}{m}$ in the other: But in the Line of Projection (ſuppoſe) $\frac{1}{m}f$ (ſuch a Part of the Force impreſſed, and a Celerity anſwerable:) in the Line of Deſcent, $\frac{1}{m}g$ ſuch a Part of the Impulſe of Gravity.

30. Thoſe for the Line of Deſcent (of the ſame Body) are all equal, each to other: Becauſe g (the new Impulſe of Gravity) in each Moment is ſuppoſed to be the ſame.

31. But what is the Proportion of f to g (that of the Force impreſſed, to the Impulſe of Gravity in each Body) remains to be inquired by Experiment.

32. This Proportion being found as to one known Force; the ſame is thence known as to any other Force (who's Proportion to this is given) in the ſame uniform *Medium*.

33. And this being known as to one *Medium*; the ſame is thence known as to any other *Medium*, the Proportion of whoſe Reſiſtance to that of this is known.

34. If a heavy Body be projected downward in a perpendicular Line; it deſcends therefore at the Rate $\frac{1}{m}$, $\frac{1}{mm}$, $\frac{1}{m^3}$, *&c.* of f (the impreſſed Force, increaſed by $\frac{1}{m}$, $\frac{1}{m}+\frac{1}{m^2}$, $\frac{1}{m}+\frac{1}{m^2}$ $+m^3$ *&c.* of g the Impulſe of Gravity, (by ¶ 7. and ¶ 27.) Becauſe both Forces are here united.

35. If in a perpendicular Projection upwards; it aſcends in the rate of the former, abated by that of the latter. Becauſe here the Impulſe of Gravity is contrary to the Force impreſſed.

36. When therefore this latter (continually increaſing) becomes equal to that former (continually decreaſing) it then ceaſeth to aſcend; and doth thenceforth deſcend at the rate wherein the latter continually exceeds the former.

37. In an Horizontal, or Oblique Projection: If to a Tangent, whoſe Increments are as *FL*, *LM*, *MN*, *&c.* that is as $\frac{1}{m}f$, *&c.* be fitted Ordinates (at a given Angle) whoſe

Increments are as *FL*, *FM*, *FN*, &c. that is, as $\frac{1}{m}g$, *&c.* The Curve anſwering to the Compound of theſe Motions, is that wherein the Project is to move.

38. This Curve (being hitherto without a Name) may be called *Linea Projectorum*; the Line of Projects, or things projected; which reſembles a Parabola deformed.

39. The Celerity and Tendency, as to each Point of this Line, is determined by a Tangent at that Point.

40. And that againſt which it makes the greateſt Stroke or Percuſſion, is that which (at that Point) is at right Angles to that Tangent.

41. If the Projection (at ¶ 27.) be not infinitely continued, but terminate (ſuppoſe) at *N*, ſo that the laſt Term in the firſt Column or Series erect be a; and conſequently in the ſecond, $m\,a$; in the third, $m\,m\,a$, *&c.* (each Series having one Term fewer than that before it:) then (for the ſame Reaſons as at ¶ 22.) the Aggregates of the ſeveral Columns (or erect Series) will be $\frac{1-a}{n}$, $\frac{1-m\,a}{n}$, $\frac{1-m\,m\,a}{n}$, and ſo forth, till (the Multiple of a becoming $=1$) the Progreſſion expire.

42. Now all the Abatements here, a, $m\,a$, $mm\,a$, *&c.* are the ſame with the Terms of the firſt Column taken backward. For a is the laſt, $m\,a$ the next before it; and ſo of the reſt.

43. And the Aggregate of all the Numerators is ſo many times 1, as is the Number of Terms (ſuppoſe t,) wanting the firſt Column; that is $t - \frac{1-a}{n}$, or $\frac{nt-1+a}{n}$; and this again divided by the common Denominator n, becomes $\frac{nt-1+a}{nn}$. And therefore $\frac{nt-1+a}{nn}$ g, is the Line of Deſcent by its own Gravity.

44. If therefore this be added to a projecting Force downward in a Perpendicular; or ſubducted from ſuch projecting Force upward; that is, to or from $\frac{1-a}{n}f$: The Deſcent in the firſt Caſe will be $\frac{1-a}{n}f +$ $\frac{nt-1+a}{nn}g$; and the Aſcent in the other caſe $\frac{1-a}{n}f - \frac{nt-1+a}{nn}g$. And in this latter Caſe, when the ablative Part becomes equal to the poſitive Part, the Aſcent is at the higheſt; and thenceforth (the ablative Part exceeding the poſitive) it will deſcend.

45. In an Horizontal or Oblique Projection; having taken $\frac{1-a}{n}f$ in the Line of Projection, and thence (at the Angle given) $\frac{nt-1+a}{nn}$ g in the Line of Deſcent; the Point in the Curve anſwering to theſe, is the Place of the Project anſwering to that Moment.

46. I am aware of ſome Objections to be made, whether to ſome Points of the Proceſs, or to ſome of the Suppoſitions. But I ſaw not well how to wave it, without making the Computation much more perplex'd. And in a Matter ſo nice, and which muſt depend upon Phyſical Obſervations, 'twill be hard to attain ſuch Accuracy, as not to ſtand in need of ſome Allowances.

47 Somewhat might have been farther added to direct the Experiments ſuggeſted at ¶ 21, and 31. But that may be done at leiſure, after deliberation had, which way to attempt the Experiment.

48. The like is to be ſaid of the different reſiſtance which different Bodies may meet with in the ſame *Medium*, according to their different Gravities (extenſively or intenſively conſidered) and their different Figures and Poſitions in Motion. Whereof we have hitherto taken no account; but ſuppoſed them, as to all theſe, to be alike and equal.

Poſt-ſcript.

49. The Computation in ¶ 41, 42, 43, may (if that be alſo deſired) be thus repreſented by Lines and Spaces. The Ablatives a, $m\,a$, $m\,m\,a$, *&c.* (being the ſame with the firſt Column taken backward) are fitly repreſented by the Segments of NF (beginning at N) in Figure 5. and 6. and therefore by Parallelograms on theſe Baſes, aſſuming the common height of Fh, or NQ; the Aggregate of which is Nh, or FQ. And, ſo many times 1, by ſo many equal Spaces, on the ſame Baſes,

ſes, between the ſame Parallels, terminated at the Hyperbola: The Aggregate of which is *hFNQn*. From whence if we ſubduct the Aggregate of Ablatives *FQ*; the remaining trilinear *hQn*, repreſents the Deſcent.

50. If to this of Gravity, be joined a projecting Force; which is to the Impulſe of Gravity as *hK* to *hF* (be it greater, leſs, or equal) taken in the ſame Line; the ſame Parallels determine proportional Parallelograms, whoſe Aggregate is *KQ*.

51. And therefore if this be a perpendicular Projection downwards; then *hKkn* (the Sum of this with the former) repreſents the Deſcent.

42. If it be a Perpendicular upwards; then the difference of theſe two repreſents the Motion; which ſo long as *KQ* is the greater, is Aſcendent; but Deſcendent, when *hQn* becomes greater; and it is then at the higheſt when they be equal.

53. If the Projection be not in the ſame Perpendicular, (but Horizontal, or Oblique) then *KQ* repreſents the Tangent of the Curve; and *hQn* the Ordinates to that Tangent, at the given Angle.

54. But the Computation before given, I take to be of better uſe than this Repreſentation in Figure. Becauſe in ſuch Mathematical Enquiries, I chuſe to ſeparate (as much as may be) what purely concerns Proportions; and conſider it abſtractly from Lines, or other Matter wherewith it is incumbered.

As to the Queſtion propoſed; whether the reſiſtance of the *Medium* do not always take off ſuch a proportional part of the Force moving through it, as is the ſpecifick Gravity of the *Medium* to that of the Body moved in it: (for, if ſo, it will ſave us the trouble of Obſervation.)

I think this can by no means be admitted. For there be many other things of Conſideration herein, beſide the intenſive Gravity (or, as ſome call it, the ſpecifick Gravity) of the *Medium.*

A viſcous *Medium* ſhall more reſiſt, than one more fluid, though of like intenſive Gravity.

And a ſharp Arrow ſhall bore his way more eaſily through the *Medium*, than a blunt-headed Bolt, though of equal Weight, and like intenſive Gravity.

And the ſame Pyramid with the Point, than with the Baſe forward.

And many other like Varieties, intended in my ¶ 48.

But this I think may be admitted, namely, That different *Mediums*, equally liquid, (and other Circumſtances alike,) do in ſuch proportion reſiſt, as is their intenſive Gravity. Becauſe there is, in ſuch proportion, a heavier Object to be removed, by the ſame Force. Which is one of the things to which ¶ 33 refers.

And again: The heavier Project once in Motion, (being equally ſwift, and all other Circumſtances alike) moves through the ſame *Medium* in ſuch proportion more ſtrongly, as is its intenſive Gravity. For now the Force is in ſuch proportion greater, for the removal of the ſame reſiſtance. And this Part of what my ¶ 32 inſinuates.

But where there is a Complication of theſe Conſiderations one with another, and with many other Circumſtances, whereof each is ſeverally to be conſidered; there muſt be reſpect had to all of them.

A

An Inſtance of the Excellence of the Modern Algebra, *in the Reſolution of the Problem of finding the* Foci *of Optick Glaſſes univerſally.*

By E. Halley, *S. R. S.*

THE Excellence of the *Modern Geometry* is in nothing more evident, than in thoſe full and adequate Solutions it gives to Problems; repreſenting all the poſſible Caſes at one view, and in one general Theorem, many times comprehending whole Sciences; which deduced at length into Propoſitions, and demonſtrated after the manner of the *Ancients*, might well become the Subjects of large Treatiſes: For whatſoever Theorem ſolves the moſt complicated Problem of the kind, does with a due Reduction reach all the ſubordinate Caſes. Of this I now deſign to give a notable Inſtance in the Doctrine of *Dioptricks*.

This Dioptrick Problem is that of finding the *Focus* of any ſort of *Lens*, expoſed either to converging, diverging, or parallel Rays of Light, proceeding from, or tending to a given Point in the *Axis* of the *Lens*, be the *Ratio* of *Refraction* what it will, according to the Nature of the tranſparent Material whereof the *Lens* is formed, and alſo with allowance for the thickneſs of the *Lens* between the *Ver-*

tices of the two Spherical Segments. This Problem being ſolved in one Caſe, *mutatis mutandis*, will exhibit Theorems for all the poſſible Caſes, whether the *Lens* be *Double-Convex* or *Double-Concave*, *Plano-Convex*, or *Plano-Concave*, or *Convexo-Concave*, which ſort are uſually called *Meniſci*. But this is only to be underſtood of thoſe Beams which are neareſt to the *Axis* of the *Lens*, ſo as to occaſion no ſenſible difference by their Inclination thereto; and the *Focus* here formed, is by *Dioptrick Writers* commonly called the principal *Focus*, being that of uſe in *Teleſcopes* and *Microſcopes*.

Let then (in *Fig.* 7. *Tab.* 5.) $BE\beta$ be a double Convex *Lens*, C the Center of the Segment EB, and K the Center of the Segment $E\beta$, $B\beta$ the thickneſs of the *Lens*, D a Point in the *Axis* of the *Lens*; and it is required to find the Point F, at which the Beams proceeding from the Point D, are collected therein, the *Ratio* of Refraction being as m to n. Let the diſtance of the Object $DB = DA = d$ (the Point A being ſuppoſed the ſame with B, but taken at a diſtance therefrom, to prevent the coincidence of ſo many Lines) the *Radius* of the Segment towards the Object CB or $CA = r$, and the *Radius* of the Segment from the Object $K\beta$ or $K\alpha = \varrho$; and let $B\beta$ the thickneſs of the *Lens* be $= t$, and then let the Sine of the Angle of Incidence DAG be to the Sine of the refracted Angle HAG or $CA\varphi$ as m to n: And in very ſmall Angles, the Angles themſelves will be in the ſame proportion; whence it will follow that,

As d to r, ſo the Angle at C to the Angle at D, and $d + r$ will be as the Angle of Incidence GAD; and again as m to n, ſo $d+r$ to $\frac{dn+rn}{m}$, which will be as the Angle GAH= CAφ, This being taken from ACD which is as d, will leave $\frac{m-nd-nr}{m}$ analogous to the Angle AφD; and the Sides being in this Caſe proportional to the Angles they ſubtend, it will follow, that as the Angle AφD is to the Angle ADφ, ſo is the Side AD or BD to Aφ or Bφ: That is, Bφ will be $= \frac{mdr}{m-nd-nr}$ which ſhews in in what Point the Beams proceeding from D, would be collected by means of the firſt Refraction; but if nr cannot be ſubſtracted from $m-nd$, it follows that the Beams after Refraction do ſtill paſs on diverging, and the Point φ is on the ſame ſide of the *Lens* beyond D. But if nr be equal to $m-nd$, then they proceed parallel to the *Axis*, and the Point φ is infinitely diſtant.

The Point φ being found as before, and Bφ—Bβ being given, which we will call δ, it follows by a Proceſs like the former, that βF, or the focal Diſtance ſought, is equal to $\frac{\delta\varrho n}{m-n\delta+m\varrho} = f$. And in the room of δ ſubſtituting $B\varphi - B\beta = \frac{mdr}{m-nd-nr} - t$, putting p for $\frac{n}{m-n}$ after due Reduction this following Equation will ariſe,

$$\frac{mpdr\varrho - nd\varrho t + npr\varrho t}{mdr + md\varrho - mpr\varrho - m-ndt + nrt} = f.$$

Which Theorem, however it may ſeem operoſe, is not ſo, conſidering the great Number of *Data* that enter the Queſtion; and that one half of the Terms ariſe from our taking in the thickneſs of the *Lens*, which in moſt Caſes can produce no great Effect; however it was neceſſary to conſider it, to make our Rule perfect. If therefore the *Lens* conſiſt of *Glaſs*, whoſe Refraction is as 3 to 2 'twill be $\frac{6dr\varrho - 2d\varrho t + 4r\varrho t}{3dr + 3d\varrho - 6r\varrho - dt + 2rt} = f$. If of *Water*, whoſe Refraction is as 4 to 3 the Theorem will ſtand thus $\frac{12dr\varrho - 3d\varrho t + 9r\varrho t}{4dr + 4d\varrho - 12r\varrho - dt + 3rt} = f$. If it could be made of *Diamant*, whoſe Refraction is as 5 to 2, it would be

$$\frac{\frac{10}{3}dr\varrho - 2d\varrho t + \frac{4}{3}r\varrho t}{5dr + 5d\varrho - \frac{10}{3}r\varrho - 3dt + 2rt} = f.$$

And this is the univerſal Rule for the *Foci* of double Convex Glaſſes expoſed to diverging Rays. But if the thickneſs of the *Lens* be rejected as not ſenſible, the Rule will be much ſhorter, *viz.* $\frac{pdr\varrho}{dr + d\varrho - prt} = f$, or in Glaſs $\frac{2dr\varrho}{dr + d\varrho - 2r\varrho} = f$. all the Terms wherein t is found being omitted, as equal to nothing. In this Caſe, if d be ſo ſmall, as that $2r\varrho$ exceed $dr + d\varrho$, then will it be $-f$, or the *Focus* will be Negative, which ſhews that the Beams after both Refractions ſtill proceed diverging.

To bring this to the other Caſes, as of converging Beams, or of Concave Glaſſes, the

Rule is ever compoſed of the ſame Terms, only changing the Signs of $+$ and $-$; for the diſtance of the Point of Concourſe of converging Beams, from the Point B, or the firſt Surface of the *Lens*, I call a negative diſtance or $-d$; and the Radius of a Concave *Lens* I call a negative Radius, or $-r$ if it be the firſt Surface, and $-\varrho$, if it be the ſecond Surface. Let then converging Beams fall on a double Convex of Glaſs, and the Theorem will ſtand thus $\frac{-2dr\varrho}{-dr-d\varrho-2rt}=+f$, which ſhews that in this Caſe the *Focus* is always affirmative.

If the *Lens* were a *Meniſcus* of Glaſs, expoſed to diverging Beams, the Rule is $\frac{\mp 2dr\varrho}{-dr+d\varrho+2r\varrho}=f$, which is affirmative when $2r\varrho$ is leſs than $dr-d\varrho$, otherwiſe negative: But in the Caſe of converging Beams falling on the ſame *Meniſcus*, 'twill be $\frac{+2dr\varrho}{+dr-d\varrho+2rp}=f$. and it will be $+f$, whilſt $d\varrho-dr$ is leſs than $2r\varrho$; but if it be greater than $2r\varrho$, it will always be found negative or $-f$. If the *Lens* be double Concave, the *Focus* of converging Beams is negative, where it was affirmative in the Caſe of diverging Beams on a double Convex; *viz.* $\frac{-2dr\varrho}{+dr+d\varrho-2r\varrho}=f$, which is affirmative only when $2r\varrho$ exceeds $dr+d\varrho$: But diverging Beams paſſing a double Concave, have always a negative *Focus*, *viz.* $\frac{-2dr\varrho}{+dr+d\varrho+2r\varrho}=-f$.

The Theorems for converging Beams, are principally of uſe to determine the *Focus* reſulting from any ſort of *Lens* placed in a Teleſcope, between the *Focus* of the Object-glaſs and the Glaſs it ſelf; the diſtance between the ſaid *Focus* of the Object-glaſs, and the interſpoſed *Lens* being made $= -d$.

I here ſuppoſe my Reader acquainted with the Rules of Analytical Multiplication and Diviſion, as that + multiplied by + makes the Product +, + by − makes −, and − by − makes +, ſo dividing + by + makes the Quote +, + by − makes −, and − by − makes +, which will be neceſſary to be underſtood in the preceding Examples.

In caſe the Beams are parallel, as coming from an infinite diſtance, (which is ſuppoſed in the Caſe of Teleſcopes) then will d be ſuppoſed Infinite, and in the Theorem $\frac{p d \varrho r}{d r + d \varrho - p r \varrho}$ the Term $p r \varrho$ vaniſhes, as being finite, which is no part of the other infinite Terms; and dividing the remainder by the infinite Part d, the Theorem will ſtand thus $\frac{p \varrho r}{r + \varrho} = f$, or in Glaſs, $\frac{2 r \varrho}{r + \varrho} = f$.

In caſe the *Lens* were *Plano-Convex* expoſed to diverging Beams, inſtead of $\frac{p d \varrho r}{d r + d \varrho - p r \varrho}$, r being infinite, it will be $\frac{p d \varrho}{d - p \varrho} = f$, or $\frac{2 d \varrho}{d - 2 \varrho}$ if the *Lens* be Glaſs.

If the *Lens* be Double-Convex, and r be equal to ϱ, as being formed of Segments of equal Spheres, then will $\frac{p\,d\,\rho\,r}{d\,r + d\,\rho - p\,r\,\rho}$ be reduced to $\frac{p\,d\,r}{2\,d - p\,r}f$; and in caſe d be infinite, then it will yet be farther contracted to $\frac{1}{2}\,p\,r$, and p being $= \frac{n}{m-n}$ the focal diſtance in Glaſs will be $= r$, in Water $1\frac{1}{2}\,r$, but in Diamant $\frac{1}{3}\,r$.

I am ſenſible that theſe Examples are too much for the compleat Analyſt, though I fear too little for the leſs Skilful; it being very hard, if poſſible, in ſuch Matters, ſo to write as to give ſatisfaction to both; or to pleaſe the one, and inſtruct the other. But this may ſuffice to ſhew the extent of our Theorem, and how eaſie a Reduction adapts any one caſe to all the reſt.

Nor is this only uſeful to diſcover the *Focus* from the other propoſed *data*, but from the *Focus* given, we may thereby determine the diſtance of the Object; or from the *Focus* and Diſtance given, we may find of what Sphere it is requiſite to take another Segment, to make any given Segment of another Sphere caſt the Beams from the diſtance d to the *Focus* f. As likewiſe from the *Lens*, *Focus*, and Diſtance given, to find the *Ratio* of Refraction, or of m to n, requiſite to anſwer thoſe *Data*. All which it is obvious, are fully determined from the Equation we have hitherto uſed, *viz.* $p\,d\,\rho\,r = d\,r\,f + d\,\rho\,f - p\,r\,\rho\,f$, for to find d the Theorem is $\frac{p\,r\,\rho\,f}{r\,f + \rho\,f - p\,\rho\,r} = d$, the diſtance of the Object.

For ϱ the Rule is $\frac{drf}{pdr + df + prf} = \varrho$.

But for p will be $\frac{drf + d\varrho f}{d\varrho r + f\varrho r} = p$, which latter determines the *Ratio* of Refraction, m being to n as $1 + p$ to p.

I ſhall not expatiate on theſe Particulars, but leave them for the Exerciſe of thoſe that are deſirous to be informed in Optical Matters, which I am bold to ſay are comprehended in theſe three Rules, as fully as the moſt Inquiſitive can deſire them, and in all poſſible Caſes; regard being had to the Signs + and −, as in the former Caſes of finding the *Focus*. I ſhall only ſhew two conſiderable Uſes of them; the one to find the diſtance whereat an Object being placed, ſhall by a given *Lens* be repreſented in a *Species* as large as the Object it ſelf, which may be of ſingular Uſe in drawing Faces, and other things in their true Magnitude, by tranſmitting the *Species* by a Glaſs into a dark Room, which will not only give the true Figure and Shades, but even the Colours themſelves, almoſt as vivid as the Life. In this Caſe d is equal to f, and ſubſtituting d for f in the Equation, we ſhall have $pdr\varrho = ddr + dd\varrho - dp\varrho r$, and dividing all by $d.\ pr\varrho = dr + d\varrho - pr\varrho$, that is, $\frac{2pr\varrho}{r + \varrho} = d$; but if the two Convexities be of the ſame Sphere ſo as $r = \varrho$, then will the diſtance be $= pr$; that is, if the *Lens* be Glaſs $= 2r$, ſo that if an Object be placed at the Diameter of the Sphere diſtant, in this Caſe the *Focus* will be as far within as the Object is without, and the *Species* repreſented thereby will be as big as the Life; but if it were a *Plano-Convex*, the ſame diſtance will be $= 2pr$, or in Glaſs to four times the *Radius* of the Convexity; but of this Method I may entertain the Curious at ſome other Time, and ſhew how to magnifie or diminiſh an Object in any proportion aſſign'd, (which yet will be obvious enough from what is here delivered) as likewiſe how to erect the Object which in this Method is repreſented inverted.

A ſecond Uſe is to find what Convexity or Concavity is required, to make a vaſtly diſtant Object be repreſented at a given *Focus*, after the one Surface of the *Lens* is formed; which is but a Corallary of our Theorem for finding ϱ, having p, d, r and f given; for d being infinite, that Rule becomes $\frac{rf}{pr - f} = \varrho$, that is in Glaſs $\frac{rf}{2r - f} = \varrho$, whence if f be be greater than $2r$, ϱ becomes Negative, and $\frac{rf}{f - 2r}$ is the *Radius* of the Concave ſought.

Thoſe that are wholly to begin with this Dioptrical Science, cannot do better than to read with Attention a late Treatiſe of Dioptricks, publiſhed by *W. Molineux*, Eſq; R.S.S. who has at large ſhewn the Nature of Optick Glaſſes, and the Conſtruction and Uſe of Microſcopes and Teleſcopes; and though ſome nicely Critical have endeavoured to ſpy Faults, and to traduce the Book; yet having long ſince examin'd it with Care, I affirm, that if I can judge, it hath but two things that with

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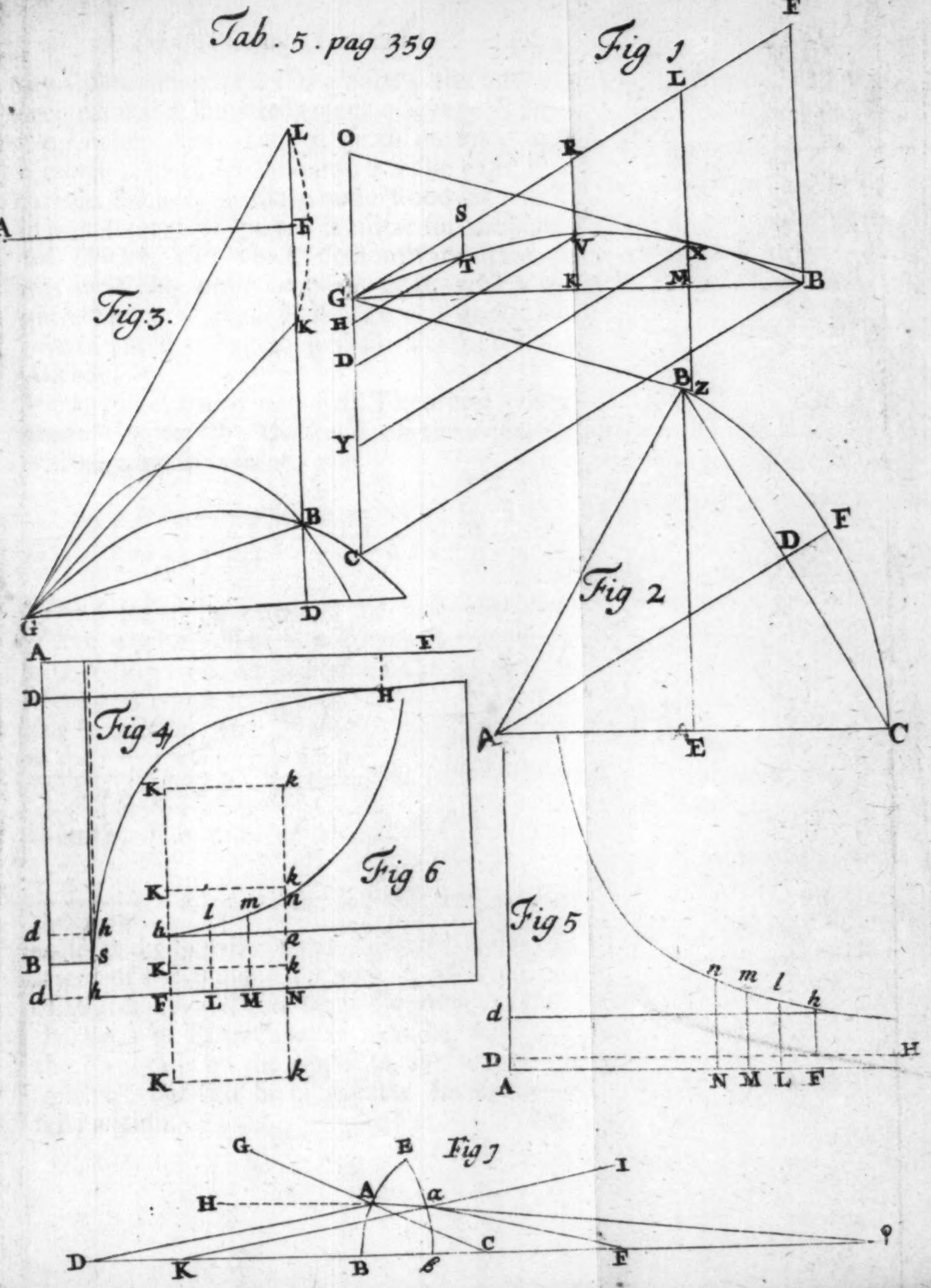
Fig 1
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any Colour may be call'd Faults; the one, an over-careful acknowledgment of every Trifle the Author had receiv'd from others; and the other, that he labours to make eaſie this curious Subject, ſo little underſtood by moſt, in a manner perhaps too familiar for the *Learned Critick*, and which demonſtrates that it was writ *cum animo docendi*, both which require but very little Friendſhip or good Nature in the Reader, to paſs for Vertues in an Author.

But to return to our firſt Theorem, which accounting for the thickneſs of the *Lens*, we will here again reſume, *viz.*

$$\frac{m p d r \varrho - n d \varrho t + n p r \varrho t}{m d r + m d \varrho - m p r \varrho - m - n d t + n r t} = f.$$

And let it be required to find the *Focus* where a whole Sphere will collect the Beams proceeding from an Object at the diſtance d: Here t is equal to $2r$ and $r = \varrho$. And after due Reduction, the Theorem will ſtand thus, $\frac{m p d r - 2 n d r + 2 n p r r}{2 n d + 2 n r - m p r} = f$; but if d be Infinite, it is contracted to $\frac{m p r}{2 n} - r = \frac{2 n - m}{2 m - 2 n} r = f$, wherefore a Sphere of Glaſs collects the Sun-Beams at half the Semi-diameter of the Sphere without it, and a Sphere of Water at a whole Semi-diameter. But if the *Ratio* of Refraction m to n be as 2 to 1, the *Focus* falls on the oppoſite Surface of the Sphere; but if it be of greater Inequality it falls within.

Another Example ſhall be when a Hemiſphere is expoſed to parallel Rays, that is, d and ϱ being infinite, and $t = r$, and after due Reduction the Theorem reſults $\frac{nn}{mm - mn} r = f$. That is, in Glaſs it is at $\frac{4}{3} r$, in Water at $\frac{9}{4} r$; but if the Hemiſphere were Diamant, it would collect the Beams at , $\frac{4}{5}$ of the *Radius* beyond the Center.

Laſtly, As to the Effect of turning the two ſides of a *Lens* towards an Object; it is evident, that if the thickneſs of the *Lens* be very ſmall, ſo as that you neglect it, or account $t = 0$; then in all Caſes the *Focus* of the ſame *Lens*, to whatſoever Beams, will be the ſame, without any difference upon the turning the *Lens:* But if you are ſo curious as to conſider the thickneſs, (which is ſeldom worth accounting for) in the Caſe of parallel Rays falling on a *Plano-Convex* of Glaſs, if the plain ſide be towards the Object, t does occaſion no difference, but the focal diſtance $f = 2r$. But when the Convex-ſide is towards the Object, it is contracted to $2r - \frac{2}{3} t$, ſo that the *Focus* is nearer by $\frac{2}{3} t$. If the *Lens* be double Convex, the difference is leſs; if a *Meniſcus*, greater. If the Convexity on both ſides be equal, the focal length is about $\frac{1}{6} t$ ſhorter than when $t = 0$. In a *Meniſcus* the Concave-ſide towards the Object increaſes the focal Length, but the Convex towards the Object diminiſhes it. A General Rule for the difference ariſing on turning the *Lens*, where the *Focus* is Affirmative, is this $\frac{2rt + 2\varrho t}{3r + 3\varrho - t}$, for double Convexes of differing Spheres. But for

Meniſci the ſame differerce becomes $\frac{2rt + 2\rho t}{3r - 3\rho + t}$; of which I need give no other Demonſtration, but that by a due Reduction it will ſo follow from what is premiſed, as will the Theorems for all ſorts of Problems relating to the *Foci* of Optick Glaſſes.

FINIS.

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